The Journal of ENGINEERING EDUCATION

October, 1958 *Table of Contents* Vol. 49, No. 1

Do You Know 2

W. T. Alexander New President of ASEE 4

Retrospect and Prospect, Presidential Address, 1958
Frederick C. Lindvall 6

Bryant New Journal and Society Editor 14

The 66th Annual Meeting 15

ASEE Awards, 1958

The Lamme Award 20
The George Westinghouse Award 22
The Vincent Bendix Award 24
The Curtis W. McGraw Award 26
The James H. McGraw Award 28
Engineering Drawing Award 28
Nomography Award 28

Society Activities

Minutes of the General Council and Executive Board 29

Section Meetings 32

Report on the Engineering Sciences

33

Departments and Notes

National Standard Examinations in Mechanics 13

Seventh Annual Instrumentation Conference 28

Teaching Positions Available 32

New Members 92

Copyright © 1958, The American Society for Engineering Education

DO YOU KNOW . . . .

► . . . . That there were over 1000 paid registrations at the Annual Meeting at Berkeley? In addition, there were about 700 women and children. This fine attendance is in general accord with the preliminary estimates of the local committee, which did a good job of planning and handled those things which must be "played by ear" with promptness and dispatch.

► . . . . That an article describing some of the major program activities of the Annual Meeting is on page 15. The major business activities of the Society are given in the abstract of the minutes of the meetings of the Executive Board and General Council on page 29.

► . . . . That Paul T. Bryant is the new Editor of the JOURNAL, having assumed that position on a half-time basis on September first? The other fifty per cent of his time is in the office of the Dean of Engineering at the University of Illinois as Assistant Editor with the rank of Instructor. For additional biographical information see page 14. The former Editor, E. C. McClintock, Jr., was on a 20 per cent basis and now devotes all of his time to his university position as Director of Engineering Information and Publications, and Editor of the Engineering Experiment Station. Professor McClintock served as Editor for three years and contributed significantly to the improvement of the JOURNAL.

► . . . . That the continued growth of the Society is reflected in the $117,290 budget for 1958–59 approved by the Executive Board? This does not include monies granted the Society for special studies. The increased income resulting from the growth of individual and industrial membership is being directed primarily to improved services to the membership and a modest contribution to the reserve for emergencies.

► . . . . That the Society now has four new publications for sale? They are:

1. Engineering Enrollment and Faculty Requirements, 1957–1967. (Also published in the May issue of the JOURNAL.)
2. Facilities and Opportunities for Graduate Study in Engineering. (Also published in the June issue of the JOURNAL.)
3. Report on the Engineering Sciences. (Also published in this issue of the JOURNAL.)
4. Research Capabilities and Potentialities. (A summary will be published in a subsequent issue of the JOURNAL.)

The price of individual copies is 25¢ each. If you wish to order any, encircle the number, write your name and address in the margin, tear out the sheet, enclose the appropriate amount, and mail to the Secretary.

► . . . . That copies of ECRC's Research Review still may be purchased for $2.00 per copy? Send orders to Renato Contini, Secretary of ECRC, Research Division, College of Engineering, New York University, New York 53, N. Y.

► . . . . That negotiations now are underway for holding five ASEE–AEC Summer Institutes for 1959? It is probable that two will be the beginning or basic course, two of an advanced nature (one might be on

heat transfer), and one a repetition of the beginning course for technical institute instructors. Information on these institutes will be sent to deans of engineering of eligible institutions as soon as possible, and appropriate notices will be in the JOURNAL. It is expected that the deans will inform their staffs of the availability of the institutes. Last year many decided in April and May that they were interested, and by then it was too late to be considered in most instances.

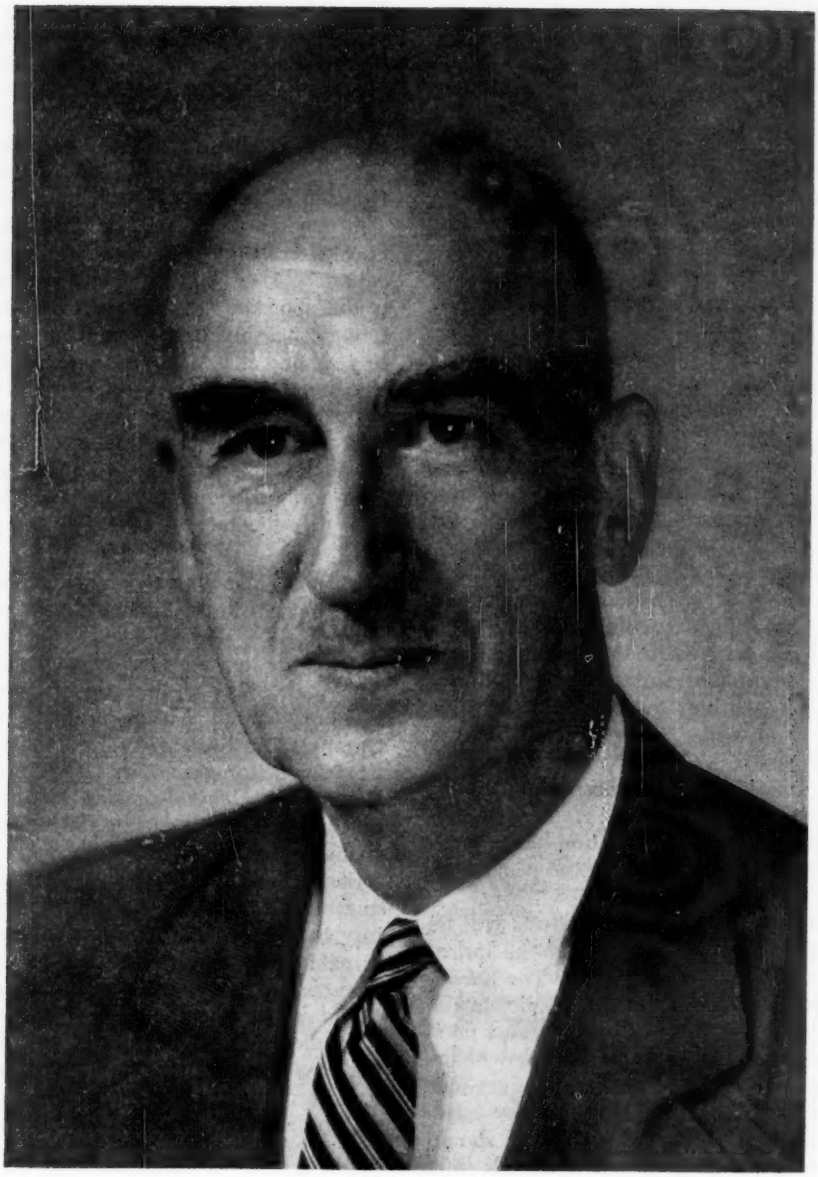
► . . . . That the ASEE Educational Mission to Russia seems certain of materializing—if the political situation permits? An eight-man team is to spend 30 days in Russia studying at least five engineering schools and the relations between the schools and industry. It is proposed that the appraisal be analogous to that of ECPD when it is requested to accredit an engineering curriculum. The general plan is for a Russian mission to come to the United States in early fall and for our group to go to Russia prior to mid-winter. The director of the project is F. C. Lindvall, and the committee aiding him is composed of W. L. Everitt and N. A. Hall. The National Science Foundation has granted the Society $29,000 for the project.

► . . . . That active efforts will be made this year to expand the industrial fellowship program? The Executive Board reaffirmed its belief in the soundness of the program. Past president M. M. Boring is the new chairman of the committee. Suggestions of companies which might be interested or should be interested should be sent to him. The Leeds and Northrup Foundation has established its third industrial fellowship; the first was awarded to Johns Hopkins University, the second to the University of Washington, and the third to Princeton University.

► . . . . That the 1959 College-Industry Conference will be held at Houston, Texas, on Jan. 26 and 27? The general theme will be "Industry Speaks Its Mind on Engineering Education." The University of Houston is the sponsor. Interest in this conference has been growing from year to year and it has become more than a regional meeting. If last year's program is any indication of what to expect this year, many will want to make plans to attend. If there has been a short-coming, it has been the lack of educators in attendance.

► . . . . That next year's Annual Meeting will be in Pittsburgh, Pa. on June 15–19? The Allegheny Section is the sponsor, and the co-chairmen are W. I. Short of the University of Pittsburgh and Walton Forstall of Carnegie Institute of Technology. ECRC is foregoing its traditional Wednesday General Session in order that the entire day can be devoted to sponsored trips to research laboratories. Each division has been requested to submit its choice of laboratory to visit, and the local committee is making the necessary arrangements. Greater use also will be made of Monday morning in order to reduce the mid-week jam of events. So, make your plans for an earlier than usual arrival; Pitt and Carnegie Tech will be ready to welcome you.

W. LEIGHTON COLLINS
Secretary



WILLIAM T. ALEXANDER
President of ASEE for 1958–1959

W. T. ALEXANDER NEW PRESIDENT OF ASEE

A man who, as President-elect of ASEE, introduces himself to the Society's section and division chairmen, with dry New England humor, as "your new errand boy," is one who is likely to wear the laurels of office gracefully. He is Dean William Thurlow Alexander of the College of Engineering, Northeastern University, President of ASEE for 1958–59.

President Alexander brings to the office years of experience as a teacher and administrator and as a member of ASEE. He began his teaching career as an instructor in mechanical engineering at Northeastern University in 1926, and he joined the Society in 1929. He received his B.M.E. degree from Northeastern University in 1926, his B.S. there in 1931, and his M.A. from Boston University in 1935. He taught at Northeastern as an instructor in mechanical engineering until 1936, as an assistant professor in industrial engineering from 1936 to 1939, and as associate professor of industrial engineering until he was called to active duty in the Navy in 1940.

During World War II, Dean Alexander saw active duty with the Navy, as an engineering officer on transports, later as a member of the staff of the Commander, Transports, Third Amphibious Force. Toward the end of the war he was Senior Naval Inspection Officer at the Todd Pacific Shipyards in Tacoma, Washington. Active in the Naval Reserve, he was advanced to the permanent rank of Captain in 1950. He has been educational advisor for the Naval Reserve Officer's School in Boston.

After returning to civilian life in 1945, President Alexander was made Professor and Chairman of the Department of Industrial Engineering and Dean of the College of Engineering at Northeastern University. His professional engineering interests include particularly the fields of heat power, metallography, materials testing, and welding engineering.

Besides his work in education, he has also gained experience in industry and has been active in consulting work in materials and heat power. In 1953–54 he was a participant in the "Year in Industry for Educators" program of the Engineering Department of the E. I. du Pont de Nemours Company. He is a member of Tau Beta Pi.

The new president has been active in various engineering societies for many years. He is a member of the Society for the Advancement of Management and a former Director of the Boston Chapter, a member of the Engineering Societies of New England and former Chairman of the Annual Meeting Committee and of the Education Committee, and a member of the Massachusetts Society for Professional Engineers and Director at Large for 1958–1961. He is a past chairman of the Boston Section of the American Society of Mechanical Engineers, and a member of the Student Development Committee of the Engineer's Council for Professional Development.

President Alexander is a New Englander, born at North Harpswell in the State of Maine, and raised there and in Brunswick. He is a quiet man and, when asked a question, is likely to have thoughtful recourse to his pipe before answering. As the Society under his leadership plays its role in an age of satellites and rising enrollments, President Alexander's expenditures for tobacco are likely to be considerable, to the benefit of the Society and of education in engineering.

RETROSPECT AND PROSPECT

Presidential Addresss, 1958

FREDERICK C. LINDVALL

President, ASEE, 1957–1958; Chairman of Engineering, California Institute of Technology, Pasadena

Presented June 17, 1958, 66th Annual Meeting, Berkeley, California

Shakespeare's plays, as the old lady said, seem to be awfully full of quotations. Without doubt an apt remark could be found from this source which would give the implication that a view in retrospect may give a clue to the future. On the other hand a more homely sage of our time, the old baseball player Satchel Paige, has a number of prescriptions for keeping one's peace of mind, among which is—"Don't look behind you, something may be catching up with you." This says something pertinent to engineering education, because technology is moving so rapidly that it may be gaining on us. We can be more comfortable if we don't look behind us, but through retrospect we may visualize what is ahead for us and for our students.

The next decade, which has just been marked by the dawn of the space age, promises to be no less exciting than the last. At no time in the history of engineering education have there been so many new concepts, new principles, and new methods introduced in such a short period of time. Novel devices, complex systems and wholly new fields of engineering development have come into being bringing with them requirements for broader fundamental knowledge and more penetrating analysis. Let us look briefly at some of the new things which now appear to a greater or less extent in engineering education which simply weren't there at all ten or so years ago. Some of these ideas, some of these devices, were a consequence of intense wartime effort and after the security wraps had been removed at the end of the war their effects began to be felt in the engineering schools. Technical articles, textbooks and personal knowledge of some of the faculty permitted rapid introduction of new material which had almost revolutionary effect on individual courses and on curricula.

Radar immediately comes to mind, with the associated micro-wave technology. This involves generation, detection and amplification of pulsed and continuous radiation in the microwave range. The circuitry itself was new to Electrical Engineering education, with wave guides commonly known as "plumbing" replacing the orthodox, understandable conductors for lower frequencies. The descriptions and understanding of generators of microwaves necessitated discussions of electron-mechanics, the bunching of electrons, as in klystrons, or the behavior of electron streams in the travelling wave tubes which soon came in as new devices for broad band amplification. The wave guides, themselves, were meaningless until interpreted in terms of wave propagation in various modes, analyzable in terms of Maxwell's equations. Up to this time Maxwell's equations were rather esoteric and limited to sophisticated courses in Electricity and Magnetism or Advanced High Frequency. Now undergraduates talk knowingly of the various modes and coupling devices and measure in the laboratory

the electrical performance of microwave equipment with meter sticks and micrometers instead of conventional indicators of current or voltage.

Electronics in general had by this time already displaced in large measure the early Electrical Engineering work directed toward power applications. Megawatts and cycles were losing out rapidly to watts and megacycles. But here, too, sweeping changes were occurring. Semi-conductor devices, the diodes, and particularly the transistors rapidly began to displace vacuum tubes. These semi-conductors immediately directed attention to basic materials and to fundamental notions of the electronic character of this peculiar type of conduction. Schools began to present something of the theory of semi-conductors, thus bringing in the quantum concepts which are basic to solid state physics. This, in turn, put pressure on the physics departments of engineering schools to modify their course work for the engineers to include some of these modern concepts.

Nuclear energy appeared as a great fireball highlighting a new technology, and Engineering Schools began eagerly to seek information on reactors and radiation effects and to assess the probable impact of fission on engineering education. In addition the possibility of fusion as an energy source has led to much speculation about the far-reaching engineering implications. The Atomic Energy Commission has assisted colleges by stimulating new educational opportunities for engineering students in subjects helpful to reactor development and application. This further enforced the desire of engineering educators to have something of modern Physics as a part of engineering instruction.

Magnetic amplifiers, saturable reactors, and other devices had proved their merit during the war, and their industrial importance was immediately perceived. This brought into Electrical Engineering instruction more penetrating consideration of magnetic properties of materials than was formerly true. In fact, the very non-linear properties which permit these new magnetic devices to function were formerly ignored or not taken seriously in the study of electrical machanes and magnetic devices. Theoretical treatment of these non-linear devices is difficult, but they and other things which involve similar properties of material have forced extensive academic consideration of analysis of non-linear systems.

Then computers came on the scene with a rush, bringing new problems for engineering colleges. The sudden demand for engineers who knew something of computers brought with it the urge to teach in the colleges courses of various kinds dealing with computer theory, development, and use. Some schools had major research programs in computers and were well equipped to offer instruction. Other schools did not try to meet this specialized demand, but all have begun to ask questions about the mathematical content of engineering curricula to see whether some of the symbolic logic and specialized algebras pertinent to computers might not be a better starting point for college mathematics than our present traditional procedure. This approach might establish early some clear concepts of logic and notions of groups and sets which would make basic concepts of some of our more familiar mathematics more understandable.

Information Theory is another new subject which came from the communication art with its problems of signals and noise, but which has far-reaching implications for all of our measuring and recording techniques,

for data handling, and communication of ideas. Here again the mathematical basis of information theory brings in probability and statistics normally not a part of engineering mathematics, but which as a single example is also vital to the work of the quality control engineer in inspection procedures and to modern vibration testing using random loading procedures.

Aeronautics has also had problems of aeroelasticity and flutter suddenly come into prominence with higher speed flight. New methods of analysis have emerged, based in large measure on computer capabilities. Thermal stress problems plague the designer of high speed aircraft and hundreds of little problems have arisen because of the extended range of environment with very high altitude flight.

Jet Propulsion has redirected engineering education toward a more theoretical consideration of physical-chemistry principles and to the basic understanding of combustion problems. Materials of motors and nose cones, as in all other high-temperature, high-performance devices, become a real limitation. Our college work in engineering materials must be re-examined and conducted on more fundamental levels of physical metallurgy and solid state physics.

Guidance and control, with related instrumentation and telemetering, focus attention on servomechanisms which must operate under extreme environmental conditions with fantastic accuracy and exceptional reliability. But, more significantly, jet propulsion and the guided missile have developed to an extent even greater than for aircraft a type of systems thinking which is the very essence of engineering.

Chemical Engineering, also, has new facets brought about in large measure by wartime nuclear work. Isotope separation, as by the gaseous diffusion method, has become a new technique; new solvent extraction schemes have evolved; ion exchange techniques have moved forward in spectacular fashion.

Structural Engineering has had less impressive, but none-the-less important advances which modify our engineering education. New methods of design and construction have appeared. Much more detailed analysis of stress is being done, and digital computer techniques are assuming greater and greater significance is advanced designs, particularly in aircraft and missile structures. Test methods and instrumentation have made remarkable advances which are rapidly replacing the traditional "busting laboratory" and giving the students new confidence and a detailed knowledge of stress distribution to verify more sophisticated designs. New schemes for construction, such as tilt-up and lift-slab, pre-stress and limit design, encourage the student to imagine still other ways of building structures and deliberately instrumenting them in the process of construction to gain new design information. Also structural engineers have become more conscious of dynamic load effects caused by wind, earthquakes, and possible blasts, and so the students of Civil Engineering are getting a new appreciation for dynamics and for the related mathematics.

Non-destructive testing with radiation and ultrasonic techniques is relatively new in our laboratories. New instrumentation has greatly extended our capabilities in research, measurement, and control. Both old and new physical principles have been adapted to sensing devices, creating whole families of transducers which have rapidly become working tools of technology as well as being beautiful examples of basic principles.

The list could go on, but I have cited enough to indicate that during the past decade much new material has been added to an already crowded curriculum, and the intellectual level of the work has been raised markedly. Also in the new engineering we find ourselves working more and more in areas earlier identified as classical physics. Solid state, spectroscopy, cryogenics, low and high pressure arc plasmas, electron mechanics and optics, physical properties of materials at extremes of temperature, are all subjects of importance in many of today's engineering developments. Then when we further intensify our interest in the humanities, we are clearly faced with such a crowded course schedule of study that some of the older engineering material must be omitted and deferred to experience learning.

Getting rid of some of the older material has not been easy. Professors have vested interests and are reluctant to give up courses which they have had fun teaching for the last fifteen or twenty years. Also, some of the professional societies have viewed with alarm the disappearance or shrinking of some of the traditional engineering college material, such as shop work, foundry, drafting, surveying, and the courses which deal with the art and practice of engineering. Not a few professional men are troubled by the young graduates of today who may not be able to earn their way immediately as designers or operators. Yet we in engineering education who are trying to anticipate the trends and the consequent educational requirements take comfort in the advice of many thoughtful engineers to concentrate in the colleges on the fundamentals, the basic sciences and engineering sciences and on the humanities, and to leave to industry the specialized training on the job or in more formal company education and orientation programs.

Thus we see that today's engineering and tomorrow's engineering require greater breadth of education and depth as well. Let me quote to you a few of the appeals in today's recruiting advertising which suggest new achievements in research, design, and production involving materials, techniques and methods not presented in textbooks or even job descriptions. These few samples will give a feeling of this climate of modern engineering. Phrases such as "a career that requires creative thinking, utilizes all your skills and talents, offers the chance to learn the latest techniques," "—want to grab the atom by the tail and put it to useful work?" "—want to dig in and really get down to the basics?" "—start today and plan tomorrow." "—up to two years of theoretical and practical training are offered." "—you will push beyond existing limitations into new concepts and new products," "—today more and more new ideas come from men trained to an awareness of that which is yet to be accomplished," "—the door to electronic wonders is only slightly ajar. The greatest discoveries lie ahead," "—seeking men educated to solve tomorrow's problems which today cannot even be stated."

The emphasis is on the new, the undiscovered ideas, devices, and systems. Creative thinking is an ideal eagerly sought and carefully nourished. Advanced ideas and methods intensify the need for a basic engineering education which has extensive scope and depth in the fundamental sciences and the engineering sciences. This basic education is a foundation, a start, for professional work to be learned in practice, and for graduate study which is becoming increasingly a necessity. Admittedly a four-year curriculum with this orienta-

tion must omit some of the engineering details which we have all been accustomed to present in our teaching and which have some immediate value to the young graduate if he happens to fall into work in the general area he has studied.

But, if our engineers of the future are to be identified with the highest levels of effort in technology, the advanced designs and the new materials and processes, we must accept the fact that a bachelor's degree program is insufficient for the highest level of professional engineering practice in the same way our colleagues in physics and chemistry expect the bachelor's degree to be an initial, rather than a terminal degree. We are all well aware of the fact that during the war many scientists distinguished themselves in work which was quite foreign to their professional experience and which they regarded as essentially engineering development or analysis in character, but which had never before been studied.

In fact, this experience has led to a certain arrogance among some scientists with respect to the competence of engineers. However, the invidious comparison overlooks the fact that at the time of World War II very few engineers had had graduate education and even fewer held the Doctoral degree, whereas these useful scientists were, for the most part, exceptionally able people who were also Ph.D.'s. Their additional education, together with maturity and research experience was of great value, but most important of all, it was sufficiently fundamental and general to be applicable to new situations and new developments. In short, the education was general, flexible, and powerful in application to new technology.

Such strength should also mark the education of our best engineers so that they may function truly as engineers in advanced development, synthesis, and design, with no handicap of a shallow base of fundamentals or weakness in analysis. Obviously, not all engineers will work at this high level, but their basic education should not exclude them from the opportunity. Indeed the opportunities and challenges are unlimited in all areas of technology. The space age with its "new dimension" clearly dramatizes the future for us and for the public, and establishes a favorable climate and receptive attitude which will be of enormous help in our efforts to strengthen engineering education.

Quality First

Thus far I have put the emphasis on quality, which should get the emphasis. As to quantity of engineering students, no one can predict. The general trend of population growth will bring an increasing number of students to the engineering colleges, even though no more than the customary fraction of college students enroll in engineering. Indices such as the number of engineers per unit of population, the number of engineers per unit of employed workers, the number of engineers per unit of gross national product or per unit of industrial productivity, all suggest that the long-term national demand for engineers will increase. However, we will see a gradual shift in the definition of an engineer.

As we begin to achieve greater professional stature in engineering, the right to use the title "Engineer" will be more jealously guarded with the result of fewer but better educated engineers entering the profession. This will be a consequence of raising admission standards in the engineering schools, with concurrent improvement in instruction to develop these better students to their full capacity. The Junior Engineer, the Engineering Aide

or Technician will begin to supplement the ranks of the engineering profession in order that the entire spectrum of engineering activity can be complete. The enrollment in engineering schools is within our control, but I suspect that it will grow despite efforts at control. However, this growth cannot be allowed to interfere with the necessary improvement in engineering education.

It is in the ach vement of this improvement that we are in most serious difficulty. We have not enough competent teachers in our engineering colleges to meet the needs of increased enrollment and higher quality of instruction. Evidently the rapidly increasing amount of graduate work will create a greater demand for more teachers with advanced degrees. Nationally a large number of advanced degree men ought to enter the teaching profession.

A special study for the ASEE by its Committee for the Development of Engineering Faculties reveals that during the next ten years, due to the normal growth of engineering student enrollment, faculty retirements, loss to industry, and for other reasons, about 9500 new teachers of engineering will be needed, or some 1000 per year. Last year a national total of 590 Ph.D. degrees in engineering was reported. A few of these new Ph.D.'s entered teaching, but if all of them had done so, the number would have been too small. Next year will not be significantly better.

Thus our problem is, first, to encourage more of the best students to enter graduate school in preparation for a career of engineering teaching and research; second, to make a teaching career as attractive, competitively, as possible with reasonable pay and good basic research opportunities; and third, to do everything possible to assist existing engineering faculties to develop professionally in the new technological directions and improve the effectiveness of their teaching. For it is only from superior teachers that we can expect to obtain the superior graduates we need. There is no substitute for quality.

In the next decade we must make an all-out effort to improve the quality of our engineering education. We will need help from all quarters. Industry, private foundations, and government should assist in the financial problems which must be met. Employers of engineers must use great restraint in drawing away from the colleges to attractive professional opportunities our best academic seed-corn. Professional engineers through their societies can be helpful by developing an understanding of the serious problems which confront the colleges in up-grading curricula, dropping old material, and introducing new material. We all at times feel that the younger generation is going to Hell, but it is the younger generation that will be doing tomorrow's engineering problems, not yesterday's or today's.

Alfred North Whitehead, the mathematician and philosopher, has some apt remarks which appear in "The Aims of Education": "A well-planned University course is a study of the wide sweep of generality. I do not mean that it should be abstract in the sense of divorce from concrete fact, but that concrete fact should be studied as illustrating the scope of general ideas. This is the aspect of University training in which theoretical interest and practical utility coincide. Whatever be the detail with which you cram your student, the chance of his meeting in after-life exactly that detail is almost infinitesimal; and if he does meet it, he will probably have forgotten what you taught him about it. The really useful training yields a

comprehension of a few general principles with a thorough grounding in the way they apply to a variety of concrete details. In subsequent practice the men will have forgotten your particular details; but they will remember by an unconscious common sense how to apply principles to immediate circumstances."

Of course we rise hastily to remark "we *are* teaching principles"—but are we doing it in the sense that Whitehead means,—with thoroughness, with the breadth and with the full meaning of rigour which is the essence of mathematical thinking? Have we examined carefully our various courses for those concepts and principles which are really fundamental—so that the entire curriculum represents an orderly sequence of development? Is our traditional academic organization by departments a handicap in achieving the kind of breadth and unity which modern education should have?

Today technology is so diffuse and so inter-disciplinary in character that it is difficult to identify the older or classical kinds of engineering—Civil, Electrical, Mechanical, etc. In fact, it has been said that our engineering colleges are organized after an engineering world which has ceased to exist and that the classical options are vestigial rather than functional. This sort of academic administration is for administrative convenience and should not really matter unless departmental fences keep the free flow of ideas and new developments from seeking their natural place in a logical curriculum pattern.

In turn, does our own ASEE organization give us the opportunity for broad perspective judgment in engineering education? We have our Divisional organization, in which people with common subject interests find a forum for exchange of ideas, but are these Divisions large enough to be functional in today's sense? For example, where does the general body of knowledge pertinent to Jet Propulsion belong in our Divisional structure? The subject matter involved would include problems of fuel chemistry, combustion, unusual problems of stress analysis and thermal stress, advanced questions of heat transfer, aerodynamics, guidance and control, shock and vibration, and instrumentation.

Or to widen the question: do we have in our Society and in our engineering schools organizational structures compatible with the broad-scale thinking necessary in our modern complex engineering systems? Indeed the description "hyper-complex" his been applied seriously in at least one recent paper! All facets of a system must be considered: machines, the environment, and the people who may be a part of that system. Conflicting requirements must be reconciled, interactions between portions of the system must be analyzed, and, despite the complexities involved, an optimum solution must be found.

True enough this process, call it systems thinking, always has been the essence of good engineering, but today's problems and tomorrow's needs require intensity and scope of effort beyond conventional engineering capability. Team-work, knowledge from many fields, and overall analysis characterize systems engineering. This is not new in principle or in pratice, but is evolving rapidly in scope, methods, and techniques. Our tightly-compartmented educational patterns unfortunately do not reflect these trends. Consciously, not by a new course labelled "Systems Engineering," but through a pervading philosophy in all of our instruction, we must lead toward this goal of broad-scale engineering analysis and synthesis which we call systems thinking.

As was well said some seventy years ago by a great engineer, A. M. Wellington, discussing the art of reconnaissance for railway location, "The young and inexperienced engineer cannot proceed on a safer hypothesis than this: that however forbidding the region, a line exists which is conspicuously better than any other, and which will in all cases be found to be—in comparison with what was expected—a line cheap to build and economical to operate." This statement taken today in the larger context of modern systems is engineering in the best sense. In the exciting prospects ahead we have this spirit of great engineering to guide us.

NATIONAL STANDARD EXAMINATIONS IN MECHANICS

During the past academic year, a committee of the Mechanics Division has been preparing a set of final examinations both in Statics and Dynamics. These examinations were prepared from a comprehensive survey of final examinations submitted by forty representative colleges from all parts of the nation.

Copies of these standard examinations will be sent to these schools early in November 1958 together with a uniform grading outline and report forms. These forms are to be mailed in a sealed envelop addressed to the committee but sent in another envelop to the Secretary of ASEE, who will then forward the enclosure to the committee so that anonymity will be preserved. Summaries of the national averages will then be mailed to each participating school so that each school will be able to determine independently its relative performance.

The committee will welcome the participation of as many colleges as possible in order to broaden the scope of this attempt to measure national competence in mechanics. *If you desire to be included in this project, please write immediately to F. L. Singer at New York University, University Heights, New York 53, New York.*

National Standard Examinations Committee

A. Higdon
H. R. Lissner
H. F. Marco
G. Pickett
W. B. Stiles
F. L. Singer, *Chairman*

BRYANT NEW *JOURNAL* AND SOCIETY EDITOR

The JOURNAL welcomes Paul T. Bryant as Society Editor. Holder of three degrees from the University of Oklahoma, and for two years technical editor at the State College of Washington Institute of Technology, he was last year serving as full-time teaching assistant while working for the doctorate in English at the University of Illinois, which will be his headquarters as Editor. Trained originally in the life sciences, he has had a varied career and background in botany, English, and engineering editing.

A native of Oklahoma, Bryant attended Oklahoma State University at Stillwater for two years, interrupted by an 18-month enlistment in the Army. He then studied botany at the University of Oklahoma, Norman, with a split zoology-chemistry minor, receiving his B.S. in 1950. He continued his graduate studies at Oklahoma, completing an M.S. in botany with a zoology minor in 1952, after which he spent a year as a teaching assistant in botany at Iowa State College, Ames.

His latent interest in English began to emerge in 1953, when he returned to Oklahoma for a year as graduate teaching assistant in freshman English, while studying for the M.A. in English and aiding in the technical writing course as well. His bias to English in engineering became solidified with two years, 1954–1956, as Technical Editor, Washington State Institute of Technology, State College of Washington, Pullman. Here his primary responsibilities included editing and arranging for the printing of technical bulletins and reports, and the proceedings of conferences held by the Institute.

For the Institute's Division of Industrial Research, which included the mining and engineering experiment stations, he also edited most of the material sent to technical journals. In addition, he handled publicity and public relations activities for the Institute, wrote and supervised publication and distribution of monthly "News Items," and worked with staff members on the preparation of articles.

Bryant is a member of Phi Beta Kappa, an Associate member of Sigma Xi, and at Oklahoma received two Phi Sigma awards as the outstanding undergraduate and graduate student in biology, 1950 and 1952. He is married, and has two children.

His selection as Editor for the Society was announced at a meeting of the Executive Board preceding the official opening of the ASEE's 66th Annual Meeting at the University of California, Berkeley. The retiring Editor of the JOURNAL, Professor E. C. McClintock, Jr., resigned to devote full time to his work as Director of Publications and Technical Information at the University of Illinois College of Engineering.

THE 66TH ANNUAL MEETING UNIVERSITY OF CALIFORNIA, BERKELEY

Material for this review article was largely drawn from the work of the Press Room at the Annual Meeting, especially the news releases. Most of these were prepared by John I. Mattill of Massachusetts Institute of Technology, Chairman of the Public Relations Committee for the Society, and Glenn Housh of the University of California at Berkeley.

The first ASEE Annual Meeting of the Space Age found the Society confronted with its usual generous quota of problems and challenges, some old and some new. But whether the matter was old or new, its consideration was undertaken with a heightened feeling for the importance of engineering science and technology in the present and future course of western civilization. With this came the realization that the interest and attention of the general public was more firmly fixed on the problems of engineering and scientific education than perhaps ever before in the history of this nation.

The problems tackled by the 66th Annual Meeting of ASEE were primarily problems of numbers and needs so large as to seem beyond all reasonable solution. From the vantage point of the annual meeting pressroom, the most urgent but still unsolved problems of engineering education in the year 1958 fall into three basic groups:

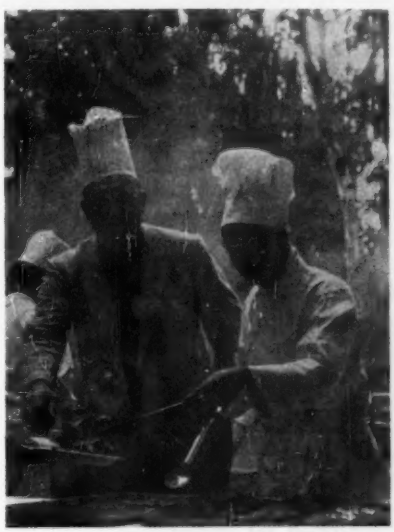
1. How to increase graduate student enrollment and engineering sciences content to meet the needs of increasingly complex technology.

2. How to increase the numbers and competence of engineering faculties, to meet the demands of fast-growing enrollment in the coming decade.

3. Where to find the financial and material resources to accomplish these ends while at the same time increasing quality—in the face of needs which may already have compromised quality at some institutions.

In pondering these problems, the meeting found no comfort in the proposals for federal aid to increase the number of undergraduates through large scholarship programs without any corresponding aid to graduate students, research, or faculties.

On the lighter side, Berkeley held back the "unusual" California weather that we hear so much about and gave the meeting a week of usual, comfortably cool nights and pleasant, not-too-hot days. The beautiful weather and the care and hospitality of the University of California hosts created an



Paul F. Keim, Trips and Entertainment Chairman, helped out Gene Endo at the Salmon Barbecue.

atmosphere in which Society members could concentrate on the problems at hand and families could enjoy sight-seeing tours and other recreation in sufficient variety for any taste.

Demand for Engineers

Mixed in with current calls for a rapidly increasing supply of engineers in the face of the Russian challenge in technology have been reports that the job situation for engineering graduates has not been favorable. Dr. Henry H. Armsby, chief for engineering education in the U. S. Department of Health, Education, and Welfare, discounted these reports with data from a survey made of June graduates from 88 colleges throughout the nation. From this information, gathered by the Engineering Manpower Commission of the Engineers Joint Council, Dr. Armsby said that three weeks prior to graduation, 71 per cent of the current crop of engineering graduates either had already accepted positions or had offers they were seriously considering. Graduates in other fields from the same colleges were much less in demand. Dr. Armsby concluded from the survey evidence that "employment possibilities for graduating engineers should remain good into the foreseeable future."

Dr. Armsby's findings were generally supported by the material presented by Harold Goldstein of the U. S. Department of Labor, who said the impression that there has been a reduction in the demand for engineers is not correct. Bureau of Labor Statistics figures compiled for the National Science Foundation show that the number of engineers employed in industry increased by 25 per cent in the three years from 1954 to 1957.

Preparation for Engineering

Since Sputnik awakened America to the scientific and educational accomplishments of our competitors, much attention has been given to elementary and secondary school preparation for college work in engineering and science. Reporting on one study of this matter, Dr. Kenneth Pitzer, Dean of the College of Chemistry at the University of California, told the Society that schools in California had been found to be accepting somewhat less than one half of the achievement in arithmetic that is expected of children in England. In a comparison of about 3,000 students in England with about 3,000 in California, fewer than 1 per cent of the California children made as high a score as the top 33 per cent of English children. "Something is different in California from its counterpart in England—and I don't think it's the children," Dr. Pitzer said.

Remedies offered by Dr. Pitzer included accelerated arithmetic programs. In the area of science and mathematics training in high school, he urged the expansion of present emergency teacher-recruiting programs, the provision by engineers of some recognition for schools and teachers who prove to be outstanding, and better salaries, particularly for science and mathematics teachers, who have other employment opportunities in these fields.

International Implications

This country's scientific and industrial competition with Russia was an important part of the scene at the meeting this year. Dr. Simon Ramo, president of the Space Technology Laboratories division of the Ramo-Wooldridge Corporation and top scientist of the Air Force's intercontinental ballistic missile and space program, told Society members that the threat of Russia's passing us in the technological race through more concentration on education is greater

than the immediate danger to our nation from Soviet space advances. Citing the speed, size, and progress of our large ballistic missile programs, Dr. Ramo said that if we gave the same emphasis to education as we give to missiles and space, we could have vastly superior technology in a decade.

The future resources of a nation, Dr. Ramo predicted, will be measured more by its brainpower than by any other resource. "In a world in which we cannot be superior in every phase of science and technology—nor can any other nation—that nation will be dominant that is the wisest in the use of its limited physical and technical resources," he said.

Technical Institutes

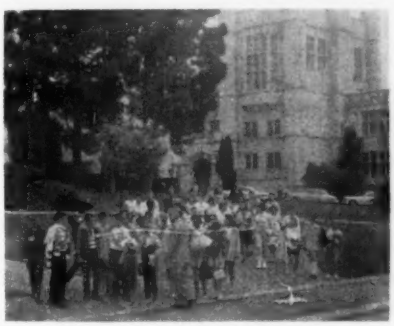
In the examination of the many facets of technical and scientific education, the potentialities of the technical institutes were carefully considered. G. Ross Henninger, President of the Ohio Mechanics Institute, said, "One of the most productive ways to increase our effective supply of professional engineers and scientists is through integrated development of engineering technicians. If we can prepare enough engineering technicians, and if we have the courage to turn over to them all the segments of yesterday's engineering and science which have become today's technology, we can release the time and energies of many of our qualified scientists and engineers."

Reporting to the Society as director of a two-year national survey of technical institute education made possible by a grant of the Carnegie Corporation, Henninger suggested that we revise the traditional two-man team of engineer and craftsman to a three-man team of engineer-technician-craftsman.

The survey found 120 educational institutions offering technical institute curricula, Henninger said. As of 1956, these schools showed enrollments of 48,000 and graduations of about 11,000 annually in engineering-related fields. "This figure," Henninger said, "represents only about 10 per cent of the presently indicated potential need."

An interesting contrast to Henninger's report was the account given by Edward E. Booher, executive vice president of the McGraw Hill Book Company, of an inspection trip to Russia to study their system of educating engineer-helpers in the technicum. According to Booher, there are almost four thousand technicums in the U.S.S.R. with an enrollment of some two million. In the current atmosphere of re-examination of our technical education system, Booher felt "we should have a careful look at some of the ideas that seem to enable the U.S.S.R. to combine our belief in mass-education with the somewhat contradictory European system of education for the few with emphasis on academic fundamentals and an intellectual elite."

Booher quotes a Russian educator as summing up the importance of the technicum by saying, "These technicums make it possible for our engi-



Acting Pied Piper Heber Newsome came over from Physical Ed. to lead the teens on campus tours.

neers and scientists to be engineers and scientists, not technicians." To Booher this meant that "effective Soviet scientific and technical manpower was being greatly expanded through the simple device of not training people for four or five or six years for jobs that can be handled by men and women trained in two or three. These are the Sputnik's helpers of which we have been ignorant."

Graduate Studies in Engineering

While the need for technicians with less training than engineers was being considered, the also pressing need for engineers with graduate training was coming in for discussion at other sessions of the Meeting. A special committee of ASEE which reported the findings of a four-year study said that engineering schools should plan for doubled and tripled graduate enrollments by 1967 if the demand is to be met.

Dean Harold E. Wessman of the College of Engineering, University of Washington, discussed the problem of getting the young engineer to go into graduate work in preference to the attractive offers made to him by industry. "Place yourself in the shoes of the bright young senior engineer," Dean Wessman said. "He may want to enroll in graduate study, but he has an offer from industry of $6000 a year. He learns that a graduate fellowship or a teaching assistantship will give him $1800 a year, if he can get one. The chances are that he is married and needs money. Is it any wonder that he accepts the industry offer?"

Teacher Shortage

With all the discussion of expanding enrollment in engineering, the supply of competent teachers of engineering constituted the topic of central interest at the Meeting. Faced with a critical shortage of engineering teachers in American colleges, the ASEE has begun a second major study of how to attract more good engineers into teaching careers and how to make those already on college faculties better teachers. Plans for the project, which will be supported by a $24,500 grant from the Ford Foundation, were announced at the Meeting by Dean Harold L. Hazen of M.I.T. Dean Hazen is chairman of the Society's Committee on Development of Engineering Faculties, which has recently completed a study of the future needs for teachers in engineering.

Reviewing an earlier committee report, Dean Hazen said that during the past school year 732 engineering teaching jobs went unfilled and that another 500 were filled by emergency part-time, temporary, or unsatisfactory personnel. "Subtle, creeping compromise with quality faculty standards is thus already reported by many deans," Dean Hazen said. He predicted that in ten years 7000 more teachers than are now on engineering faculties will be required and that 2700 of today's faculty will leave the teaching profession, so engineering colleges will need nearly 10,000 new teachers by 1967.

School Facilities

The problem of providing adequate laboratory and classroom facilities for the increase in enrollment also came in for consideration at the Meeting. Dean Elmer C. Easton of the Rutgers University College of Engineering reported that operation of an engineering college on a year-round instead of two-semester basis would make possible a more efficient use of instructional facilities. He said that the year-round plan could produce up to 56 per cent more degrees per year, increase use of college facilities by 30

per cent, and increase faculty salaries approximately 30 per cent.

At the same time, Dean Easton pointed out that the year-round system would make it necessary to give up such summer activities as conferences, symposia, and short courses, reduce faculty vacations to four weeks, possibly alter the traditional starting time and vacation periods for students, and for maximum advantage, enforce uniform distribution of students among several entering classes per year.

A Well-Organized Meeting

With an assist from the climate of the Bay Area, the University of California hosts of the 66th Annual Meeting made the visitors feel welcome and comfortable. General Chairman E. D. Howe and Vice Chairman and Secretary H. W. Iversen deserve a great deal of credit for overseeing the operation. Naming all the others who worked hard and did much to make the Meeting the success that it was would much more than fill the available space, but they all have the gratitude of those who were their guests in June. A few sample names from this large group are E. P. DeGarmo, whose housing committee arranged comfortable lodging for all, J. W. Kelly, whose printing and publicity committee was of great help in press-room activities, and Mrs. P. F. Keim and Mrs. E. D. Howe, whose women's and young people's program committee made the Meeting so enjoyable for the families of ASEE members.

The Annual Banquet at the Claremont Hotel provided a dressup event in the generally informal Meeting. Award winners are in the foreground, officers in the back.

THE LAMME AWARD

The Lamme Award consists of a gold medal and bronze replica bestowed annually upon a distinguished engineering educator for excellence in teaching and contributions to the art of teaching; contributions to research and technical literature; achievements which contribute to the advancement of the profession; and engineering administration. The Lamme trust fund was established in memory of Benjamin Garver Lamme.

LINTON ELIAS GRINTER, born in Kansas City, Missouri in 1902 and now Dean of the Graduate School and Director of Research at the University of Florida, Gainesville, has devoted thirty years of outstanding achievement to engineering education. He started his teaching career as an Associate Professor of Civil Engineering at the Agricultural and Mechanical College of Texas in 1928. By then he had graduated from the University of Kansas, received the M.S. and Ph.D. degrees (structural engineering) from the University of Illinois, and had two years of industrial design experience. His academic rise was rapid, and at age 35 he became Director of Civil Engineering and Dean of the Graduate School of Armour Institute of Technology; two years later he became Vice President and Dean of the Graduate School.

But Dean Grinter's contributions cannot be measured by a mere tracing of his career. His activities as a consultant to government agencies, and as an active participant in the American Society for Engineering Education and other professional societies have involved him in important developments in engineering education in its broadest sense. A prolific author, he has advanced the frontiers of knowledge in numerous books, papers, and monographs, and has extended his teaching beyond his own classrooms by means of several widely used texts.

A member of ASEE since 1930, Dean Grinter has never missed an annual meeting and has held important national, divisional, and sectional positions within the Society. His participation in ASEE committee work has included the chairmanship of the Graduate Division; the Committee on Improvement of Teaching, 1950–52; the Graduate Study Committees, 1943–45 and 1950–52; and the Chairmanship of the Committee on Evaluation of Engineering Education, 1952–55. He helped organize both the Texas Section and the Civil Engineering and Graduate Divisions, was Chairman of the Illinois-Indiana Section, and served two terms on the General Council. These activities culminated in his election to a vice presidency in 1950 and to the presidency of the society in 1953.

To LINTON ELIAS GRINTER, *teacher, researcher, author, consultant, and administrator, for his untiring efforts to improve engineering teaching, advance engineering knowledge, and promote the work of governmental, academic, and professional engineering organizations; for his textbooks and other writings; and for his continuous service to ASEE, especially his contributions as Chairman of the Committee on the Evaluation of Engineering Education, we present this thirty-first Lamme Award.*

Among the government agencies which Dean Grinter has served in various capacities are the War Manpower Commission, The Argonne National Laboratory, The Research and Development Board of the Department of Defense, the Civil Defense Administration, the Naval Research Laboratory, the National Science Foundation, the President's Committee on Occupational Safety, the U. S. Office of Education, the National Research Council of the American Academy of Science, and the Office of Ordnance Research.

Space does not permit an exhaustive listing of his activities in any area, for he has been tireless in his efforts to improve engineering teaching, advance engineering knowledge, and promote the work of engineering organizations engaged in administrative, educational, and research endeavors. His publications, primarily in the theory, design, and analysis of structures, have made significant contributions, among them the development of the method of determining wind stresses in skyscrapers and an early explanation of the design of reinforced concrete pavements. His most recent work has dealt with plane stress problems and the design of continuous frames.

Dean Grinter, or "L.E." as he is known to his friends, says his life-long hobby has been "reading, writing, and arithmetic." Certainly his successful professional life has been devoted to the same subject. Though he was a golf enthusiast at one time, not even six years in the Florida sunshine have encouraged him to try again for that hole-in-one.

THE GEORGE WESTINGHOUSE AWARD

The George Westinghouse Award was established by the Westinghouse Educational Foundation in 1946 as an annual Award to young engineering teachers of outstanding ability to recognize and encourage their contributions to the improvement of teaching methods for engineering students. The award consists of $1,000 in cash and an appropriately engraved certificate.

WILLIS WALTER HARMAN was born in Seattle, Washington in 1918. Since starting his teaching career in 1948, he has donned many hats. As professor of electrical engineering at Stanford University, he not only directs undergraduate E.E. instruction and staffing, but also conducts a graduate seminar for students interested in teaching. He also is a very effective member of a seven-man committee that administers Stanford's general education program for all students in the University, as well as a supplementary general studies program for Arts students. In addition, Professor Harman is Chairman of the Committee on Engineering Science and has guided the development of interdisciplinary courses that serve all engineering students at Stanford. Perhaps his most significant accomplishment as an engineering educator is the strength and success of the program in engineering science in the Stanford School of Engineering.

A University of Washington graduate in electrical engineering, Dr. Harman spent three years in industry as a test engineer before serving in the U. S. Navy from 1941 to 1945. He returned to his studies at the conclusion of World War II, this time as research associate at Stanford University where he earned the M.S. degree in physics and, in 1948, the Ph.D. in electrical engineering. He became an acting assistant professor of electrical engineering at Stanford in 1948, and in 1949 accepted an appointment as associate professor at the University of Florida. He returned to Stanford in that capacity three years later and was appointed to the rank of professor in 1957.

As a classroom teacher Dr. Harman is unsurpassed. His greatest interest is in undergraduate teaching, for he enjoys most the beginning electrical engineering courses required of all engineering students. He also teaches advanced, specialized subject matter, and has acquired a student following throughout the University in courses outside the engineering curriculum. He teaches two such courses, always as an overload. One, titled "Modern Science and Modern Man," is designed to give a greater appreciation of science to Arts students; the other, "The Human Potentiality," is designed to broaden the

To WILLIS WALTER HARMAN, *for his enthusiastic work in undergraduate education and his leadership in graduate study and research; for his sympathetic work with students, both those in the major fields of engineering and those in other disciplines; for his interest in general education; for his contributions to the literature of his field; and particularly for his imaginative view of the future of engineering education, we present this thirteenth George Westinghouse Award.*

horizons of graduate engineering students.

Although teaching, administration, and committee work limit the amount of time he can devote to research, Dr. Harman regularly directs the doctoral research of several graduate students, and has himself produced two textbooks and a number of technical articles. *Fundamentals of Electronic Motion* was published in 1948 and *Principles of Electric Circuits* in 1954. His keen judgment in matters dealing with education and electrical technology is evidenced by his having been selected as Associate Consulting Editor of the Electrical and Electronic Engineering series of books established by the McGraw-Hill Book Co.

Dr. Harman's honorary and professional associations include Sigma Xi and Tau Beta Pi. He has been a National Research Council Fellow and has been appointed to lecture at the Royal Technical University of Denmark during the coming year.

ATTWOOD APPOINTED DEAN AT MICHIGAN

Stephen S. Attwood, Professor and Chairman of Electrical Engineering at the University of Michigan, was appointed Dean of the University of Michigan College of Engineering last July. He had been serving as Acting Dean since July 1, 1957, following the death of Dean George Granger Brown.

Dean Attwood has been a member of ASEE since 1926.

THE VINCENT BENDIX AWARD

The Vincent Bendix Research Award consists of a gold medal and citation conferred annually for outstanding research contributions, either in original thought or administrative leadership, to a staff member of the colleges of engineering in the United States. The Award was established through the efforts of the Engineering College Research Council and the Bendix Aviation Corporation. The latter granted funds to establish the Award in 1956.

HUNTER ROUSE of the State University of Iowa is the first man to receive two major awards of the American Society for Engineering Education. He was the recipient of the George Westinghouse Award in 1948, and his many accomplishments since that time now bring him further recognition by the Society.

Dr. Rouse was born in Toledo, Ohio in 1906 and is a graduate of the Massachusetts Institute of Technology, where he received the S.B. degree in civil engineering in 1929. Upon graduation he was awarded the M.I.T. Traveling Fellowship in Hydraulics and spent the next two years in Europe studying under the late Professor Theodor Rehbock at the Technische Hochshule Fridericiana in Karlsruhe. He returned to M.I.T. as an assistant in hydraulics in 1931—teaching, continuing research, and writing both an S. M. thesis for M.I.T. and the Dr. Ing. dissertation for Karlsruhe. The doctoral degree was awarded in Germany in 1932, at which time he toured European hydraulic laboratories before returning with his newly won bride to the United States.

After another year of teaching and research at M.I.T., Dr. Rouse accepted an instructorship in civil engineering at Columbia University, where he participated in the establishment of a small fluid mechanics laboratory. In 1936 he joined the staff of the Soil Conservation Service at the California Institute of Technology, teaching part time as an assistant professor of fluid mechanics. During this period he published "Fluid Mechanics for Hydraulic Engineers," an Engineering Societies Monograph, and was awarded the 1938 Norman Medal of the American Society of Civil Engineers for his paper, "Modern Conceptions of the Mechanics of Fluid Turbulence."

In 1939 Dr. Rouse became Professor of Fluid Mechanics at the State University of Iowa, and in 1944, Director of the Iowa Institute of Hydraulic Research. During the years of World War II he supervised much research for the Army, Navy, and Office of Scientific Research and Development. He still is a consultant for the Corps of Engineers and the Office of Naval Research, and continues to direct a large laboratory staff in fundamental and applied research

To HUNTER ROUSE, *for his visionary utilization of scientific principles in fluid mechanics, including dimensional analysis, and his successful efforts in gaining widespread acceptance for these methods; for his leadership in training a group of students who themselves have demonstrated high achievement; for his many publications and continued scholarship; for his war-time contributions to problems of propeller cavitation and airport fog dispersal; and for his consistent support and advancement of engineering college research, we present this third Vincent Bendix Award.*

---

on many different phases of fluid motion. This activity is combined with the teaching of mechanics of fluids to graduate students and the direction of M. S. and Ph.D. dissertations.

Among the valued associations of his lifetime, Dr. Rouse lists Professors Wilhelm Spannhake, Boris A. Bakhmeteff, Vannevar Bush, and Theodore von Kármán, all of whom had highly constructive influences upon his career.

His publications include "Elementary Mechanics of Fluids," "Basic Mechanics of Fluids" with J. W. Howe, and "History of Hydraulics" with S. Ince. He also edited "Engineering Hydraulics" and is editor and coauthor of "Advanced Mechanics of Fluids," now in press. He has published many additional technical papers and discussions.

Graduate fellowships, a Fulbright Research Scholarship, and exchange professorships have taken Dr. Rouse to most of western Europe, South America, and the Philippines. As the holder of a National Science Foundation Senior Post-Doctoral Fellowship for 1958–59, he and his wife and two children leave again, in August, for three months each in Göttingen, Rome, Cambridge, and Paris.

THE CURTIS W. McGRAW AWARD

The Curtis W. McGraw Research Award was established to recognize outstanding early achievements by engineering college research workers and to encourage the continuance of such productivity in the future. The award was sponsored by the Engineering College Research Council with the assistance of the McGraw-Hill Book Company. The award consists of $1,000 in cash and an appropriately engraved certificate.

CEDOMIR M. SLIEPCEVICH is a young engineering educator whose prolific research and contributions to engineering science began long before he received his Ph.D. in Chemical Engineering from the University of Michigan. Now Professor and Chairman of Chemical Engineering and Associate Dean of the College of Engineering at the University of Oklahoma, Dr. Sliepcevich, at 38, has had a productive career in research, consulting, teaching, industrial practice, and university administration.

He first attended Montana State College, holding at that time both a university scholarship and the AIME National Scholarship. After two years he transferred to the University of Michigan to study Chemical Engineering and obtained his B.S. and M.S. degrees. While working toward the Ph.D. he was employed as a research associate in the Research Institute of the University of Michigan. He worked on a number of classified projects and also served as a private consultant on problems related to atomic energy, proximity fuse, and high-pressure gas sampling.

A part-time instructorship was accepted in 1943, and in 1946 he became a full-time instructor in thermodynamics. His doctoral research, on the design, construction and operation of a high-pressure, high-temperature continuous chemical reaction plant, was completed in 1946, but he continued on the faculty of the University of Michigan, becoming an associate professor of chemical and metallurgical engineering in 1951. Dr. Sliepcevich took leave from the University during 1952–53 to accept an industrial position as senior chemical engineer, and in 1955 accepted a position at the University of Oklahoma. It was just one year later that he was given the full responsibility, as Associate Dean, for all engineering college research activities, graduate study, accreditation, and faculty recruitment.

Dr. Sliepcevich has published about forty technical papers, including three volumes of mathematical tables, and holds several patents. Most of his publications are in the field of light scattering, high-pressure design, and reaction kinetics. He also has made significant research contributions in cooperation with the University of Michigan Medical School; his work

To CEDOMIR M. SLIEPCEVICH, *for his rare ability of stimulating teaching; for his profound research work in chemical engineering in addition to his many administrative duties as an associate dean and chairman of a department; for his development of one of the best light-scattering laboratories in the world; for his broad new concepts in treating thermodynamics; for his many contributions to technical literature; and for his future promise of significant research contributions, we present the second Curtis W. McGraw Research Award.*

in this area has dealt primarily with fundamental experimental studies on ultrafiltration as related to the artificial kidney and streaming potential as applied to blood flow measurements. At present he is an active consultant to three large industrial companies.

The son of Yugoslavian emigrants, Dr. Sliepcevich received his elementary and high school education in the public schools of Anaconda, Montana, where he was valedictorian of his class, won the state competition for mathematics majors, and earned the Bausch and Lomb Science Award. Like his two sisters, one of whom is a librarian and the other a professor of health and physical education, he learned early to cherish the value of intellectual achievement.

NEW OFFICERS FOR ENGINEERS JOINT COUNCIL, INC.

The officers for Enginers Joint Council, Incorporated, elected July 10 at the EJC, Inc. Meeting in New York, are:

President—ENOCH R. NEEDLES
Vice President—O. B. J. FRASER
Treasurer—E. LAWRENCE CHANDLER
Secretary—E. PAUL LANGE
Assistant Secretary—L. K. WHEELOCK

This was the first meeting of Engineers Joint Council, Incorporated, which replaces Engineers Joint Council, a voluntary unincorporated association. Dean E. C. Easton of Rutgers represented ASEE at this meeting.

THE JAMES H. McGRAW AWARD

KARL O. WERWATH
Milwaukee School of Engineering

Each year the Technical Institute Division presents to an outstanding contributor to Technical Institute education the James H. McGraw Award. Established in 1950 by the McGraw-Hill Book Co., in memory of James H. McGraw, the award consists of $500 and an appropriately engraved certificate.

ENGINEERING DRAWING DIVISION AWARD

HENRY CECIL SPENCER
Illinois Institute of Technology

By means of a certificate the Engineering Drawing Division acknowledges the many distinguished services rendered by a teacher of Engineering Drawing and expresses its deep appreciation for those services.

THE NOMOGRAPHY AWARD

DONALD F. OTHMER CHARLES J. MOLINARY
PAUL W. MAURER RONALD C. KOWALSKY
The Polytechnic Institute of Brooklyn

An award for the best published nomogram is periodically awarded by the Engineering Drawing Division, in cooperation with industry. The award for this year is $100 contributed by the Barber-Colman Company.

SEVENTH ANNUAL INSTRUMENTATION CONFERENCE

The School of Engineering, Louisiana Polytechnic Institute, Ruston, Louisiana, will hold the Seventh Annual Instrumentation Conference on the campus on November 6–7, 1958.

Abstract of the

MINUTES OF THE JUNE, 1958 MEETINGS OF THE GENERAL COUNCIL AND EXECUTIVE BOARD

W. LEIGHTON COLLINS

Secretary, ASEE

Copies of the complete minutes can be obtained from the office of the Secretary on request.

The General Council and Executive Board met for a total of twelve or more hours during the Annual Meeting at the University of California at Berkeley. This abstract of the minutes of those meetings is intended to inform you, the individual members of the Society, of the principal actions taken, so that you will know what happened. A complete copy of the minutes of either governing body, including the reports of officers, may be obtained on request from the Office of the Secretary.

The most significant item in all deliberations was the spontaneous questioning of the adequacy of the present divisional structure of the Society to adjust to or incorporate the new areas and techniques of engineering. The Executive Board heard a preliminary report from the vice presidents for divisions, and authorized the establishment of a committee to study the problem further. The Constitution and By-laws Committee and the Planning Committee submitted essentially the same type of recommendations. Each group was in agreement that ASEE should take the initiative in "areas of science" that are rapidly becoming "engineering" and incorporate them in its programming and organization. This is particularly true if ASEE is to attract and keep in its membership outstanding young engineering faculty members.

The adequacy of the present YET organization also was discussed from several points of view. Should the young teachers be set apart? Is the paper contest adequate stimulation and recognition, or shall there be other local or national means of recognizing effort and ability? The energy and enthusiasm of young men is required if the Society is to be vital and exert a significant influence.

The YETs did a good job on the membership campaign! 1059 individual members joined during the year, bringing the membership total, as of June 30, 1958, to 8828. The Executive Board requested the YETs to continue their efforts next year on a clean-up basis, because 21 of the 153 active institutions had no new members during the year, because the average for such institutions was only about five, and because the largest number of new members for any member institution was about 43. Thus, despite the fine showing for the year, the potential for new members is still great. Only 127 members resigned during the year and 172 were dropped from membership for non-payment of dues for two years. 362 members are delinquent one year's dues.

The interest in industrial membership increased during the year, particularly as a result of the distribution of 7000 copies of a new brochure. The Executive Board complimented the Industrial Membership Committee on its fine work, but also charged it with continuing its efforts to achieve

significant increases in this type of membership.

Because of the fine growth of membership, the financial operations for the year were satisfactory. Disbursements were about $1000 below the budget, and receipts about $1400 above the budgeted amount. This surplus and the unallocated reserve enabled the reserve for emergencies to be increased by $5000, bringing the total to $65,000. This still is below the 75 per cent of a year's operating cost recommended by the Finance Committee, but the addition enables the fund to keep pace with the increase in the budget.

The budget for next year is $117,–290, an increase of about $11,500 over the previous year. The increase results primarily from three factors: the purchase of office equipment for the Editor, an increase in the allocation for the emergency reserve, and an increase from 50 to 75 per cent in the time the Secretary devotes to ASEE during the academic year. This increase in the time of the Secretary is compatible with the previously approved increase in time, 20 per cent to 50, that the Editor devotes to ASEE throughout the year. Thus the headquarters staff should be better able to handle the increased activity which has manifested itself in all aspects of the Society's work.

Some indications of these increased activities already have been referred to. Other indications are the reports of special studies published during the year. Each of the following reports now may be purchased from the Secretary's office for 25¢ each (please send payment with the order):

1. A Survey of Research Capabilities and Potentialities.
2. Engineering Enrollment and Faculty Requirements, 1957–1967.
3. Facilities and Opportunities for Graduate Study in Engineering.
4. The Engineering Sciences and Analysis and Design.

The number of pages printed in the JOURNAL OF ENGINEERING EDUCATION was perhaps the largest in the history of the Society. A reasonably satisfactory production schedule was developed and adhered to, and all issues were published in the appropriate month.

That the Society will not remain static in its interests is evidenced by the new projects approved. They may be listed as:

1. An ASEE Exchange Mission with USSR on Engineering Education. The State Department has given its approval and funds are being sought from the National Science Foundation.

2. Co-sponsor, with ASTM, a one-day session, at the next annual meeting, on trends in the teaching of materials.

3. Authorization to negotiate a visiting scientists program with the National Science Foundation. This would be similar to the programs of the American Chemical Society, etc.

4. Authorization to the International Relations Committee of ECAC to develop a program and seek financing for a coordinated study of the 16 independently conducted International Cooperation Administration programs which are now in effect and which have many mutual problems.

5. An allocation of $250 to the Educational Methods Division for preliminary work in developing a research project on the teaching-learning function in engineering education. The money is to be returned to the Society when a comprehensive program is financed.

6. The Executive Board reaffirmed its belief in the soundness of ASEE's

industrial fellowship program and restated its desire to have the program actively promoted.

7. The resolution, "Be it resolved that Federal Tax laws should be revised to encourage greater voluntary contributions to higher education by reducing the relative cost of giving for those with low incomes to that realized by high-income taxpayers." The Executive Board also was directed to study further the matter of income tax for teachers.

Other significant actions were:

1. Discharge of the YET Summer Institute committee at its own request. The action was taken because of inability to develop a feasible plan. The idea, however, is good and will not be dropped from Society consideration.

2. The name of the Engineering Drawing Division was changed to "Engineering Graphics," at the request of the Division.

3. The Physics Division requested ASEE to study the report "Physics in Engineering Education," prepared by the American Institute of Physics Teachers at the suggestion of ASEE, and submit to AIPT a critical appraisal.

4. An experimental program for financing the comprehensive program of the Pacific Southwest Section was approved. Up to $7500 per year is to be solicited from local industry.

5. Honorary membership was awarded Dwight David Eisenhower and Nathan Washington Dougherty.

6. A three-day summer school of the Industrial Engineering Division to be held in conjunction with the 1960 Annual Meeting at Purdue University was approved.

7. The invitation of the United States Air Force Academy to hold the 1962 meeting at the Academy was accepted. This action had the endorsement of all the colleges of engineering in the area, for none, by itself, has adequate facilities.

8. A procedure for preparing and handling questionnaires used in the name of ASEE was developed.

9. The appropriate vice presidents were instructed to gather information on divisional financing, and the Board referred to the Constitution and Bylaws Committee the question regarding the right of a Division to accept funds without the knowledge and consent of the Society and without depositing such funds with the Society.

10. The new constitution for Engineers Joint Council was approved.

11. Fall meetings scheduled are:

Executive Board—Chicago, Ill., Sept. 7.
—Washington, D. C., Nov. 13.
General Council—Washington, D. C., Nov. 14.

The Washington meetings are in conjunction with the meeting of the American Association of Land Grant Colleges and State Universities.

SECTION MEETINGS

Section	*Location of Meeting*	*Dates*	*Chairman of Section*
Allegheny	Pittsburgh, Pa.	June 1959	J. R. Smith, Univ. of Pittsburgh
Illinois-Indiana	Bradley University	May 1959	R. E. Gibbs, Bradley University
Kansas-Nebraska	Univ. of Nebraska	Oct. 1958	F. J. McCormick, Kansas State College
Michigan		May 1959	M. M. Ryan, Lawrence Institute of Technology
Middle Atlantic	City College of New York	Oct. 1958	K. J. Moser, Stevens Institute of Technology
Missouri Arkansas		April 1959	A. W. Schlechten, Missouri Sch. of Mines
National Capital Area		May 1959	K. C. Harder, Office of Naval Research, Navy Dept.
New England	Harvard University	Oct. 10–11	G. A. Marston, Univ. of Mass.
North Midwest	Univ. of Wisconsin	Oct. 24–25	T. J. Higgins, Univ. of Wisconsin
Ohio	Univ. of Dayton	April 1959	M. L. Graney, Univ. of Dayton
Pacific Northwest	Montana State College	May 1959	G. J. Herman, Montana State College
Pacific Southwest	U. S. Naval Postgrad. School, Monterey, Calif.	Dec. 1958	I. J. Sandorf, Univ. of Nevada
Rocky Mountain	Utah State University	Apr. 24–25, 1959	C. H. Milligan, Utah State Univ.
Southeastern		April 1959	J. C. Reed, Univ. of Florida
Southwest	New Mexico A & M	Mar. 26–27, 1959	I. W. Santry, Southern Methodist U.
Upper N. Y.-Ontario	Univ. of Toronto	Oct. 31–Nov. 1	G. F. Tracy, Univ. of Toronto

TEACHING POSITION AVAILABLE

ASSOCIATE PROFESSOR, ASSISTANT PROFESSOR, OR INSTRUCtor to teach Highways, Highway Materials, and other Civil Engineering subjects. MS or PhD preferred, but BS degree considered. Rank and salary dependent upon qualifications. Appointment available immediately or January. Write to: Head, Civil Engr. Dept., University of Akron, Akron 4, Ohio.

REPORT ON

THE ENGINEERING SCIENCES

Mechanics of solids

Mechanics of fluids

Transfer and rate processes

Thermodynamics

Electrical sciences

Nature and properties of materials

and Engineering analysis and design

1956-1958

AMERICAN
SOCIETY
FOR
ENGINEERING
EDUCATION

American Society for Engineering Education

FOLLOW-UP COMMITTEE
(ad hoc)
ON
EVALUATION OF ENGINEERING EDUCATION

CHAIRMEN

W. L. Everitt (1955-56) B. R. Teare, Jr. (1956-57)
Ernst Weber (1957-58)

MEMBERS

C. S. Crouse H. L. Hazen
T. H. Evans F. C. Lindvall
L. E. Grinter J. H. Rushton
B. R. Teare, Jr.

TASK GROUP CHAIRMEN

Mechanics of solids	P. F. Chenea
Mechanics of fluids	V. L. Streeter
Transfer and rate processes	R. R. White
Thermodynamics	N. A. Hall
Electrical sciences	T. L. Martin
Nature and properties of materials	Glenn Murphy
Engineering analysis and design	D. W. Ver Planck

The membership of the individual task groups is listed at the beginning of each of the respective reports.

This project was financed in part by contributions from the constituent societies of ECPD, the Engineering Foundation, the General Electric Company, and the National Science Foundation.

Additional copies can be obtained by writing to Porfessor W. Leighton Collins, Secretary, American Society for Engineering Education, University of Illinois, Urbana, Ill. Price: Individual copies 25¢ each; in lots of 50 to 100, 20¢ each; in lots of 100 or more, 12¢ each.

TABLE OF CONTENTS

Preface 36

Introduction 37

Mechanics of solids 39

Mechanics of fluids 45

Transfer and rate processes 48

Thermodynamics 61

Electrical sciences 68

Nature and properties of materials 72

Engineering analysis and design 77

Preface

The final report by the Committee on Evaluation of Engineering Education was issued June 15, 1955. Because of mounting discussion of the section devoted to the engineering sciences, it was deemed desirable to elaborate further on this section, and an *ad-hoc* Follow-up Committee on the Evaluation Report was appointed by ASEE President N. W. Dougherty during the summer of 1955. Early in 1956 seven task groups were appointed to cover the six engineering sciences individually, as well as the quite distinct and separate topic of engineering analysis and design. Tentative reports of these task groups were discussed at a full meeting of the Follow-up Committee at the University of Michigan, December 2-4, 1956, and were subsequently presented at the ASEE Annual Meeting, June 17, 1957, at Cornell University. In October, 1957, it was decided to circulate these reports to the engineering schools for discussion in local committees, and comments were invited. Forty-two institutional committees replied. The report presented here has benefited considerably from their comments, in overall presentation as well as in the reports of the individual task groups.

INTRODUCTION TO

THE ENGINEERING SCIENCES

Concept of Engineering Sciences

By common agreement basic science includes mathematics, physics and chemistry, as well as such fields as geology, biology, bacteriology, and disciplines in the broad field of natural philosophy. Basic science is often referred to as pure science if the objective is specifically the establishment of fundamental knowledge about nature and its phenomena, preferably expressed in quantitative relationships.

Engineering science has its root in basic science, but carries knowledge further toward applicability. It delves into the more practical situations, illuminates these with logical reasoning based upon the fundamental laws and generic principles of basic science, and leads into the statement and methods of solution for problems fundamental in engineering analysis, design and synthesis. The continual progress in advancing the frontiers of basic science brings with it the need for continuous development in engineering science by early assimilation of the new scientific knowledge. Thus, areas of scientific research will be considered basic in their early stages of exploration, but may well become parts of engineering science after such maturity has been reached as to permit the translation into applications.

The quantitative formulation of the laws and generic principles of engineering science utilizes mathematics as a universal language, with different vocabularies in the different sectors of the science. The recognition of this fact in terms of analogies, or in terms of recurrent principles can contribute significantly to teaching efficiency.

The Engineering Sciences

The division of engineering science into sectors of readily manageable scope is, of course, arbitrary and might vary in time or with viewpoint. In the Report on Evaluation of Engineering Education, six sectors were considered desirable, namely:

1. Mechanics of solids (statics, dynamics, and strength of materials)
2. Fluid mechanics
3. Thermodynamics
4. Transfer and rate mechanisms or processes (heat, mass, and momentum transfer)
5. Electrical theory (fields, circuits, and electronics)
6. Nature and properties of materials (relating atomic, particle and aggregate structure to properties)

After discussion from many angles, such a view is still held by this committee, particularly because the division indicated above emphasizes some areas in which recent scientific contributions have added considerable scope and in which assimilation of basic science subject matter is of importance. It must be recognized, however, that any subdivision is a matter of convenience rather than necessity. *The important aspect remains that the sum total of all enumerations is intended to encompass all of engineering science.*

In admitting the dynamic nature of basic science and, therefore, of engineering science, room must be left for additions, courage must be summoned for deletions, and ingenuity should prevail for transferance of concepts and principles.

Above all, no one need mistake the

six sectors identified as the engineering sciences as individual courses to be shown in the curricula of any or all of the departmental divisions. This warnwarning appeared specifically in the Report on Evaluation of Engineering Education but bears repetition here to prevent misinterpretation.

The Reports of the Task Groups

To elucidate the admittedly brief statement on the engineering sciences in the Report on Evaluation of Engineering Education, six task groups were requested to formulate their ideas of what might constitute the appropriate scope of each individual engineering science. No attempt was made to correlate the approaches beforehand or to impose restrictions upon the thinking of the groups. It was realized that any groups, no matter how selected, would choose different boundaries, different emphases, different modes of expression. Yet, it was felt that, indeed, this diversity would lend emphasis to the objectives of the whole report, namely:

- to stimulate thinking and experimentation rather than to give the impression of finality;
- to arouse individual approaches rather than to indoctrinate uniformity; and
- to challenge new textbook writing rather than to perpetuate the traditional ones.

In order to assist in the interpretation of these task group reports, each gives a brief introduction to state the premises upon which it was composed. These introductions take into account many of the helpful comments and criticisms which were generously supplied by forty-two local institutional committees of engineering schools all over the country. We are most grateful to all of these committees for the time and effort devoted to the first draft of the task group reports, in spite of the relatively short time that could be allowed.

From the overall point of view of the committee it appears important that the basic concepts and principles which in their sum total make up engineering science, be taught in some form, in some course, at some time, to each engineering student in order to enable all engineering students to cope with the problems they will meet, especially in the earlier stages of their professional careers. It is more important, from this same point of view, to concentrate upon concepts and principles, appropriately illustrated by engineering problems, than to elaborate on special equipments and devices which are subject to rapid obsolescence.

We hope that this report will be accepted in the spirit in which it is rendered, namely:

- as a stimulant for thinking and experimentation in the interest of better engineering education;
- as an illustration of diversified approaches to the diverse topics; and
- as a study appropriate at this time but not so final as to preclude further developments in the field of engineering education.

We hope that this report will *not* be taken as a literal guide to the solution of any local curriculum problems; as a maximum standard of course content; or as a rigid set of topics for the evaluation of any curriculum.

MECHANICS OF SOLIDS

Particles, Rigid Bodies, and Deformable Solids

COMMITTEE:
P. F. Chenea, Chairman
J. P. Den Hartog
D. C. Drucker
N. J. Hoff
Jesse Ormondroyd
Reinhardt Schuhmann, Jr.
J. O. Smith
Dana Young

INTRODUCTION

The study of engineering mechanics contributes in two important ways to the engineering curriculum. First, it offers an opportunity to introduce the engineering methodology, and second, it offers an opportunity to understand the laws of motion. It is axiomatic that an acceptable treatment of engineering mechanics for engineering students takes advantage of both of these opportunities.

Methodology

An engineer must be able to observe the physical world and abstract from it a simplified model relevant to the questions to be answered. He must then analyze the model to obtain the desired answers, using the appropriate facts, techniques, and physical principles. Finally, he must relate the answers obtained from the analysis of the model to the real physical problem. Engineering mechanics is one of the first subjects in the curriculum which offers an opportunity to develop student skill in this methodology. Furthermore, engineering mechanics is a desirable vehicle for the introduction of this methodology since its models are relatively easy for the beginning student to understand.

LAWS OF MOTION

The heart of a treatment of engineering mechanics is Newton's laws of motion, or equivalent statements, which can usually be stated precisely in very brief form. The remainder of the courses in engineering mechanics is not a question of more subject matter, but rather a question of developing a better understanding of these laws and skill in their application in solving engineering problems. This skill and understanding is developed by applying these laws to a variety of situations, many of which individually may not be vital subject matter for all engineers but which serve as sound pedagogical instruments. In short, the test of a good course in engineering mechanics is not really a question of what subject matter has been included, but rather one of how good an understanding has been imparted to the student and how facile the student has become in applying the laws of motion.

Thus, it is apparent that a wide range of topics may be considered suitable subject matter for a satisfactory course in engineering mechanics. A

choice is best made by the individual institution in recognization of the needs of its students and the strength and shortcomings of its teaching staff. This is not to say that any subject matter will do. Some common faults observed in the selection of subject matter for engineering mechanics courses are:

1. The topics treated are all taken form a single field, thus failing to illustrate the scope and power of the laws of motion.

2. The subject matter is heavily laden with practical details which obscure the fundamentals of the subject.

3. The mathematical tools brought to bear on the various topics obscure the physical phenomena. This practice may, for example, bury a subject dealing with vector quantities in arithmetic, or embalm it in unnecessary higher analysis.

4. The subject matter is not integrated with the students' previous physics course or with later courses in the curriculum. In the latter case, it may provide a poor foundation for fluid mechanics, control, design, etc.

To provide some guidance in the subject matter of mechanics of solids, this body of knowledge is described below. It is not intended that this outline define a course, or even several courses, but rather that it indicate the nature of the subject matter and provide a few examples which are indicative of the innumerable topics available.

The subject matter may be divided into three areas:

1. *The description of the physical world in the mechanical sense.* Under this heading is included the vocabulary necessary for an adequate qualitative description of mechanical phenomena and the definitions of quantities, dimensions, and units required for a quantitative treatment of the motion of matter and the associated force fields.

2. *Kinematics.* Kinematics is the study of the geometry of motion and/or configuration of a mechanical system as a function of time without reference to the causative factors.

3. *Kinetics.* Kinetics is the study of the relation between forces and the resulting motion and/or configuration of a mechanical system. It is based upon certain empirical laws known as Newton's laws of motion, or equivalent statements.

This description of subject matter, while complete in a sense, is quite abstract; it becomes meaningful and useful only through its applications to certain physical models. The two simplest models which approximate real situations of interest to the engineer are the particle model and the rigid body model. These models, because of their simplicity and utility, have proved to be the best "teething ring" for beginning the study of the laws of motion. Indeed, it is sound to assume that a thorough understanding of the behavior of these models is tantamount to an understanding of the laws of motion.

The Single Particle

The *model* of a particle stems from the concept of a mass at a point. Due to the lack of geometric size, rotations are unimportant and thus the chief value of particle mechanics lies in the treatment of problems in which rotations can be ignored.

Some of the fundamental *concepts and notions* in this area of knowledge are:

1. Mass
2. Displacement
3. Velocity
4. Acceleration
5. Momentum
6. Force
7. Particle paths
8. Work
9. Potential energy
10. Kinetic energy
11. Impulse
12. Phase plane
13. Hodograph plane

14. Friction
15. Free-body diagram
16. Constraint
17. Conservative system
18. Dissipative system
19. Static stability
20. Dynamic stability
21. Force fields
22. Action at a distance
23. Relative motion

The basic *approach* used in the solution of the problems in particle mechanics rests upon the direct application of the science of kinematics and kinetics to the particle model.

Some typical *theorems* which result from the study of single particle mechanics are:

1. Impulse-momentum theorem (linear)
2. Work-energy theorem
3. Conservation of energy
4. Virtual work
5. Kepler's laws of planetary motion
6. D'Alembert's principle

Some important *problems* which can be treated by single-particle mechanics are:

1. Equilibrium of concurrent forces
2. Impact without rotation
3. Single particle orbital motion
4. Simple harmonic motion and vibration.
5. Ballistics of particles in gravitational, electrostatic, and magnetic force fields
6. Ballistics in resisting mediums

Systems of Discrete Particles

The *model* of a system of discrete particles is that of an assemblage of single particles which may or may not interact on each other.

Some of the fundamental *concepts and notions* in this area of knowledge, in addition to those enumerated for the single particle are:

1. Angular momentum
2. Moment of a force
3. Angular impulse
4. Phase space
5. Degrees of freedom
6. Center of mass
7. Center of gravity

The *approach* used in the solution of problems in multiple-particle mechanics rests upon the direct application of the science of kinematics and kinetics to this model.

Two typical *theorems* which result from the study of systems of discrete particles, in addition to those employed in single-particle mechanics, are:

1. Impulse-momentum (angular)
2. Liouville's theorem
3. Motion of the center of mass

Some typical *problems* which can be treated by the methods of multiple-particle mechanics are:

1. Many cases of planetary motion
2. Kinetics of gases
3. Flow of granular media
4. Aircraft flight patterns
5. Missile interceptor trajectories
6. Vibration of chains, trains and machines
7. Simple traffic models
8. Determination of certain properties of solids that can be represented by linear oscillators
9. Neutron diffusion

The Rigid Body

The *model* of the rigid body may be defined in two entirely equivalent forms:

(a) It may be a system of particles connected by rigid weightless bars
(b) It may be a finite piece of matter considered to be internally continuous.

In the latter case, all of the concepts associated with particles are associated with parts of the continuum of differential size. From either of these points of view the essential property of a rigid body is that the distance between any two separate points in the body remains constant under all conditions.

Some additional fundamental *concepts and notions* associated with the mechanics of a rigid body are:

1. Moment of inertia
2. Principal of axes
3. Rotation about axes
4. Density

The basic *approach* used in rigid-body mechanics is that of applying the laws of motion to its individual infinitesimal elements. Integration of these laws of motion over the whole of the rigid body leads directly to the fundamental equations covering the motion of rigid bodies.

The principal *theorem* which results from the study of a rigid body is that concerning motion of its center of mass and rotations about axes through the center of mass.

Some important *problems* which can be treated by rigid-body mechanics are:

1. Trajectories of missiles of finite size
2. Motion of a gyroscope
3. The operation of machines and mechanisms
4. The motion of ships, automobiles, and aircraft
5. Certain problems in astronomy

The second broad class of models of importance to the engineer are those in which the body is deformable and continuous. These models differ from the rigid body model in that individual points within the body may suffer relative motion. The variation in relative position of these points is a function of the properties of the material, the time history of the forces applied to the body, and the constraints on the motion. In the mechanics of deformable media the physical properties are idealized. Several such idealizations are considered for solids. The more important of these at the present time are:

1. Linear elasticity
2. Perfect plasticity
3. Work-hardening plasticity
4. Linear visco-elasticity

The mechanics of deformable media is concerned with the study of:

1. Basic concepts of stress and strain and an introduction to their interrelations during elastic and inelastic behavior of materials
2. The relation between loads and deformations
3. The relation between loads and stresses
4. The use of these idealized solutions in conjunction with observed behavior in order to introduce the student to a rational method of design

Mechanics of Materials

Mechanics of materials treats deformable solids from the simplest permissible point of view. A useful, often an excellent, first approximation to the behavior of actual solid bodies is obtained along with an understanding of the basic physical concepts.

The principal *model* utilized in mechanics of materials is that of a simple linear elastic solid, though other models are used to represent inelastic beheavior.

Some of the fundamental *concepts and notions* in mechanics of materials are:

1. Deformation
2. Internal forces
3. Strain (normal and shear)
4. Stress resultants (forces and moments)
5. Static determinancy
6. Static indeterminancy
7. Stress fields
8. Stress at a point
9. Strain at a point
10. Elastic action
11. Inelastic behavior
12. Stored energy
13. Energy dissipation
14. Elastic and inelastic instability
15. Limit load
16. Work hardening
17. Creep
18. Relaxation

The basic *approach* in mechanics of materials utilizes the relations between stress and strain and the laws of motion. From these, the basic relations between the stress resultants and deformation are derived and applied to the solution of problems of engineering interest. Each derivation follows a standard pattern. A simple assumption is made concerning the geometry of the deformation (kinematics) so that the strain pattern in the model can be computed. A simplified stress-strain relation then determines the distribution of stress. Finally, the equations of motion or equilibrium give the desired relations. Problems are solved by some form of integration or summation, taking into account the loading and constraints.

Some of the fundamental relations and *theorems* which result from a study of mechanics of materials are:

1. The relation between axial forces and axial elongations (or the time rate of axial elongation) or bars.
2. The relation between bending moment and curvature (or the time rate of curvature) for beams and plates.
3. The relations between twisting moments and the rate of twist for a bar of circular cross section.
4. The theorem of virtual work specialized to the one-dimensional problems of bars, beams, trusses, and frames and to the simplest of the two-dimensional problems of plates and membranes.
5. The theorem of Castigliano for linear systems, or more generally, the theorems of minimum complementary energy and minimum potential energy.
6. Maxwell's reciprocal theorem for linear elastic systems.
7. Theorems of limit analysis and design, for assemblages of bars including trusses and frames.
8. Certain procedures for the integration of basic relations, such as area moment techniques and conjugate beam methods.

Some important *problems* which are treated in mechanics of materials are:

1. Stresses and deflections produced in straight and curved bars which are pulled, bent, twisted.
2. Vibrations of beams and shafts.
3. Buckling of bars, beams, frames, and trusses.
4. Cylindrical and spherical shells under interior pressure.
5. Stresses in, and deflections of, frames, trusses, and plates.
6. Vibrations of plates.
7. Rotating disc problems, such as determination of stress and strain in the elastic range, limiting speed for failure, creep at constant speed, etc.

Theory of Elasticity

The principal *model* of the theory of elasticity is a homogeneous, continuous and isotropic deformable body obeying Hooke's law of proportionality between stress and strain, without damping and limited to small deformations. To this model most of the theory applies. In some cases where this model does not suffice, more complete and complicated idealizations are used which drop some of the above limitations, i.e., damping is not neglected, the deformations are no longer small, and the body is non-isotropic. Still more general models consider combinations of these three generalizations.

There are essentially no *new concepts or notions* in the theory of elasticity which are not present in mechanics of materials. The essential difference lies in a more rigorous treatment and a more complete description of the behavior of elastic solids.

The usual *approach* to the theory of elasticity is through an adequate kinematic description of the deformation, the application of the laws of motion, and the relations between stress and strain. These physical laws are expressed in mathematical form, which results in par-

tial differential equations. Characteristically, the solution of a problem in elasticity starts with a boundary value problem involving partial differential equations. To these equations a number of solutions have been found in the course of history and other new ones can be obtained by superposition of the known solution, sometimes in series form. Other powerful approaches are through energy considerations, minimum principles, and by numerical methods such as the relaxation method. Tensor mathematics is a natural tool to be applied. For the host of practical problems to which no analytical solution can be found, experimental methods are available, notably photoelastic techniques and the method of strain measurement by various types of gages.

Some of the *problems* to which the theory of elasticity has been applied, and which are instructive and important applications of the theory, include the following: Generalized theory of beams with associated shear stress distribution; St. Venant's theory of torsion; membrane stresses in thin shells; thick-walled cylinders and rotating discs; bending of thin and thick plates; curved shells, thermal stresses in structures; stress distributions in the vicinity of cracks and other local disturbances; idealization of complicated structures into combinations of elements such as beams and plates or shells; natural vibration frequencies of various structures; wave propagation in one, two, or three dimensions and stability and buckling of various structures.

Other important problems for which the classical model of elasticity is inadequate, and to which one of the more general models mentioned above apply, are the mechanics of rubber, for which large deformations are essential; the propagation of waves in damped media; the mechanics of crystals and other non-isotropic substances, and the mechanics of porous elastic media saturated with a fluid.

Theory of Plasticity

There are no new *concepts or notions* in the theory of plasticity which are not present in mechanics of materials. The essential difference lies in a more rigorous treatment and a more complete description of the behavior of plastic solids.

The usual *approach* to the theory of plasticity is again through an adequate kinematical description augmented by the equations of motion and the relations between stresses and strain (or strain rates). As in the theory of elasticity, the solution of a problem in plasticity starts with the treatment of a boundary value problem involving partial differential equations.

Some of the typical *problems* that have been treated by the theory of plasticity are:

1. Bending of a prismatic bar (beam) with rectangular cross section.
2. Twisting of a prismatic bar of any cross section (sand heap analogy).
3. Thick-walled cylinder with internal pressure, the thick-walled sphere with internal pressure, rotating discs, etc.
4. A variety of plane strain problems that may be involved in such practical operations as sheet-drawing, strip-rolling, sheet-extrusion, etc.
5. Contact pressure problems, such as the blunted wedge, etc.
6. Propagation of plastic waves in a prismatic bar, etc.

MECHANICS OF FLUIDS

COMMITTEE:

V. L. Streeter, Chairman
R. C. Binder
W. C. Nelson
Hunter Rouse
A. H. Shapiro
R. L. Sweigert
J. K. Vennard

INTRODUCTION

Some need for an understanding of the behavior of fluids at rest and in motion pervades every branch of engineering, and the subject of fluid mechanics has reached an extraordinary degree of ramification. Specialized ideas and methods have been developed to meet particular problems in the fields of civil engineering, mechanical engineering, aeronautical engineering, chemical engineering, meteorology and oceanography, acoustics, and magnetohydrodynamics. It is quite evident that an introductory course cannot begin to cope with this diversity. But it is equally true that there is a common core of fundamental ideas, conceptual models, and basic principles on which the diversity is built. Effectively grasped, this core endows an individual with the capacity and, even more, the intellectual courage, to approach problems in fluid motion with some degree of effectiveness and competence.

The undergraduate work in fluid mechanics, whatever else it may do, should aim at this core of ideas, models, and principles. Moreover, it should do so in a manner which best arms the student to confront the variety of situations which, sooner or later, he must face. Although the cultivation of flexibility and generality is implied by these statements, this need not interfere with motivation and illustration in professional fields. The important thing in this balance is that practical examples be chosen and presented, not alone for their own sake but for their aptness in demonstrating the use and power of the fundamentals.

Within this context of general principles, the instruction in fluid mechanics could be given in any one of several departments, or in several simultaneously. Furthermore, provided that the content and spirit of the fundamentals here referred to are made an integral part, the undergraduate instruction may proceed in some depth along one of many directions.

It would be self-defeating and devitalizing to avoid or to denigrate practical problems. But these should be introduced as an integral part of the scheme to create in the student a potential, in terms of intellectual and psychological fitness, for dealing with practical problems of increasing scope and variety.

There is some paradox in the fact that, in order to equip students to meet many types of situations, one may be obliged to reduce rather than expand the amount of subject matter in the curriculum. This comes about because resourcefulness in an engineering science depends uniquely on a firm grasp of those so-called elementary concepts and principles which are in fact the really difficult parts of any discipline. If they are indeed to be grasped, time must be taken to wrestle with them for their

own sake, and this may require that somewhat less attention be given to particular problem-solving skills which have become traditional. What is asked for here is that we face the fundamentals squarely without evading their difficulties. This is the surest way toward engendering both confidence and ability.

ESSENTIAL SUBJECT MATTER

This discussion of essential subject matter pertains to the undergraduate curriculum in fluid mechanics, not necessarily to any single course.

Introductory Material

This portion of the subject matter has a threefold task:

1. To correlate the science of fluid mechanics with those engineering sciences directly related to it—primarily the mechanics of solids, but also thermodynamics and properties of materials.
2. To differentiate fluid mechanics from other engineering sciences by virtue of the distinguishing properties and behavior of fluid matter.
3. To introduce on an elementary basis the aspects of dimensional reasoning which should be common to all engineering science, but are most needed in fluid mechanics because of the various properties involved.

Fundamental Concepts and Principles of Fluid Motion

The fundamental *concepts* are: velocity at a point, and the velocity field; stream lines; local and convective acceleration; mass density; normal and tangential stress; and body forces. The fundamental *principles* are: the principle of mass conservation as embodied in the continuity theorem; and the Newtonian laws of motion as embodied in the equations of flow, including the momentum theorem and the theorem of mechanical energy for regions of space.

Effects of Fluid Inertia

Many of the important aspects of fluid motion may be introduced by investigating a model in which the only force influencing the motion is that due to pressure gradients. This model may be explored at various levels, including the elementary pressure-velocity relationship for unsteady or non-uniform flow, vortex motion, and irrotational flow.

Effects of Fluid Weight

With the treatment of hydrostatic loading in the initial course in statics, the effects of fluid weight, or gravity, in fluid motion can be more broadly treated in terms of the three-term Bernoulli equation, as a superposed hydrostatic pressure in combined flow and an accelerative force in unconfined flow. Free-surfaced conditions may be exemplified by deep-water waves, by open-channel phenomena, or by more general density stratifications in the atmosphere, ocean, or settling basin, with the Froude number as the key parameter.

Effects of Fluid Viscosity

To the extent that turbulence is a viscous phenomenon, or that molecular and eddy viscosities are parallel concepts, this section includes both non-turbulent and turbulent motion. Particular emphasis is placed on surface and form resistance of immersed bodies and of conduits, with the Reynolds number as the key parameter, as well as on highly viscous flows in which the fluid density is unimportant. Essential topics are laminar and turbulent shear, boundary-layer theory, form drag, resistance of smooth and rough surfaces.

Effects of Fluid Elasticity

To the extent to which the compressibility of a gas can be treated like that

of a liquid this phase of flow belongs to fluid mechanics rather than to thermodynamics. However, there are pertinent analogies between sound waves and gravity waves that should be understood in terms of the Mach and Froude numbers as key parameters. Moreover, the extent to which liquids and gases can be treated as incompressible with negligible error should be evaluated in terms of the simple gas equation.

In every instance, emphasis should be placed upon principle and its widespread application. Such matters as manometers, Pitot tubes, and flow meters should be introduced as applications rather than as bases for flow classification. Either laboratory or class demonstrations are important in presenting the material. Many laboratory periods or class demonstrations are not necessary. Quantitative demonstrations in which students are asked to develop data which they have seen taken are good. The laboratory work should require the student to develop his own methods of taking data, evaluating it, and discussing it insofar as it is practicable.

All of the foregoing divisions are deemed essential to the engineering student's education. It is in their applications that the pedagogical flexibility and ingenuity lie.

TRANSFER AND RATE PROCESSES

COMMITTEE:
R. R. White, Chairman
L. N. Canjar
T. H. Evans
W. L. Everitt
R. G. Folsom
A. L. London
W. R. Marshall
J. R. Rushton
R. E. Treybal

INTRODUCTION

This report has the following objectives:

1. To identify and briefly describe the subject matter which constitutes the area of engineering science known as "transfer and rate processes."
2. To outline the concepts, principles, and definitions around which transfer and rate processes may be organized.
3. To indicate possible amplification of the principles by a few typical problems of engineering significance.

The material discussed in this report and its organization does not describe, nor is intended to suggest, specific course outlines or syllabi, which are better developed by individual teachers considering the philosophies and curriculum of their respective institutions. It is not intended that the subject matter developed here necessarily be made the basis for any single course or series of courses. However, the *ad hoc* committee feels that an elementary treatment of most of the topics should be found somewhere in all engineering curricula leading to the bachelor's degree. The intention here is merely to indicate the minimum extent of instruction to which all engineers should be brought. It is understood that, within certain areas, various branches of engineering may carry some of the material to higher levels.

The engineering science, "transfer and rate processes," deals primarily with the rates at which changes in the enthalpy (or internal energy) and composition of matter occur. Heat transfer processes involve the rate of change of enthalpy (or internal energy). Mass Transfer processes involve the rate of change in the composition of a mixture by the physical transport of one of its component species. Chemical kinetics deal with the rate of change in composition due to chemical reactions. Heat and mass transfer processes in turbulent fluids are related to the shear stresses in the fluids, so that momentum transfer, referring to these shear stresses, is often included as a rate process.

The transfer of electrical energy is not included in rate processes since it has developed extensively and separately as an engineering science.

Heat Transfer Changes in Enthalpy or Internal Energy

Almost all manufacturing processes require that the temperature, pressure and sometimes the relative amounts of phases be altered for a number of possible reasons, such as to induce chemical reaction, to provide an easy method of transporting material, to provide a means of separation, etc. A convenient way of accomplishing some of these re-

sults is to transfer energy to or from the system as heat. *Heat transfer* may be described in terms of at least three mechanisms referred to as *conduction, convection,* and *radiation.*

Change of Composition

Composition may change in one of two principal ways: (a) by the addition or subtraction of material to a phase via "mass transfer," and (b) by chemical reactions through which certain chemical species of a phase transform into other species.

An example of *mass transfer* is the distillation of crude oil to produce pure hydrocarbons such as ethane, propane, butane, or hydrocarbon mixtures, such as gasoline, kerosene, furnace oil, tar, etc. Other separation operations involve the movement of one component of a phase through the phase to its boundary, as in stripping propane from absorber oil where the propane has to move through the oil to its boundary so that it can be removed into a gas phase. Another example is the drying of paper where water must move through the fibers of the paper to the surface before it can escape into the drying air.

Mass transfer may be described in terms of at least three mechanisms referred to as *Diffusion, Convection,* and *Radiation.*

These transfer and rate processes are important to all engineers. For example, the civil engineer encounters problems of chemical reaction and heat transfer in the setting of concrete in dams, water treatment, and in problems of the shielding of nuclear reactions (chemical reaction, heat and mass transfer). All engineers are plagued by corrosion problems which involve chemical reaction, heat and mass transfer. The aeronautical engineer typically must handle problems of combustion (chemical reaction), and the cooling of high-speed aircraft and missiles (heat transfer). The mechanical engineer is vitally involved with combustion, corrosion, cooling of engines, lubrication, and the evaporation of fuels into air or oxygen, all of these involving the rate processes.

OUTLINE OF TRANSFER AND RATE PROCESSES

The following outline summarizes the concepts, principles, definitions and techniques which may be included in transfer and rate processes.

I. Concepts, Principles and Definitions
- A. Descriptions and Definitions
  1. Bulk transport and momentum transfer—relation of fluid mechanics to transfer processes
  2. Heat transfer
  3. Mass transfer
  4. Chemical reaction rate
- B. The Rate Equation and the Associated Concepts of Pontential and Resistance
  1. Equilibrium, non-equilibrium (2nd law of thermodynamics)
     - (a) Potential gradient
     - (b) Potential difference
  2. Resistance and conductance
     - (a) Conductive and diffusional, characterized by potential gradient
       - (1) Electric conduction current—resistivity and conductivity
       - (2) Heat transfer—conductivity
       - (3) Mass transfer—diffusivity
       - (4) Momentum transfer—viscosity
     - (b) Convective, characterized by potential difference
       - (1) Heat transfer coefficient

(2) Mass transfer—diffficient
(3) Chemical reaction velocity constant
(c) Radiation
(1) Thermal energy and photons
(a) Fourth power potential
(b) Emmissivity, reflectivity, transmissivity, absorptivity
(c) Relative geometry
(2) Mass

C. Required Principles from Thermodynamics and Mechanics
1. Conservation of mass
2. Conservation of energy
3. Dynamical equations (Newton's laws)
4. Second law of thermodynamics—irreversibility of transfer processes
5. Equations of state

II. Amplification of Principles by Problems of Technical Significance
A. Techniques
1. Differential and integral calculus, introduction to partial derivatives
2. Circuit, methods, multiple resistances
3. The methods of analogues
4. Numerical and graphical analysis, relaxation, flow and potential lines
5. Graphical representation of potential difference — operating and equilibrium lines
6. Dimensional reasoning

B. Examples
1. Steady state
(a) Heat transfer (one and two dimensional flow)
(b) Mass transfer (one and two dimensional flow)
(c) Fluid friction associated with convective transfer processes
(d) Simultaneous heat and mass transfer
2. Unsteady State
(a) Heat transfer (one dimensional flow)
(b) Mass transfer
(c) Chemical and nuclear reactions

PEDAGOGICAL CONSIDERATIONS

Techniques

The subject matter of transfer and rate processes should be so presented as to utilize fully the mathematical skills of the student.

The circuit methods of analysis, so well developed in the basic courses in electricity, provide a powerful tool for graphically visualizing steady-state transfer-rate processes involving more than one rate equation. The thermal circuit, for instance, can be used to picture the various thermal resistances in their proper relationships to the temperature potential for situations involving several conduction and convection processes in series and/or in parallel. For two-dimensional conduction problems the same circuit notions, in differential or finite difference form, lead to the methodology used in numerical (relaxation) methods. For grey-body thermal radiation between a number of surfaces the resistance network method is again a powerful tool of analysis. To extend the circuit method to transient conduction problems it is necessary only to include capacitance effects, and lumped parameter approximations, for one-dimensional conduction problems provide very simple and quite useful results for an introductory treatment with only the use of ordinary linear differential equations.

Together with circuit techniques,

graphical visualization of the current flow and potential lines for two-dimensional steady-state problems provides both a powerful tool and an integration with the flow-net techniques of fluid mechanics and field theory of electricity. It leads naturally to the use of electrical and fluid-flow analogs for experimental solutions of "difficult" two-dimensional boundary value problems.

The operating-line and equilibrium-line technique used in chemical engineering technology for the design of mass-transfer equipment has wide application in transfer and rate processes. The diagrams present a simple graphic illustration of the pertinent considerations stemming from the first and second laws of thermodynamics, together with the potential function for the rate equation. Thermodynamically limited performance of an ideal mass or heat exchanger is also evident, so that the concept of exchanger effectiveness or efficiency is clearly described.

The invaluable procedures of dimensional reasoning may be effectively utilized in the subject matter of transfer and rate mechanisms for the purpose of converting units, or for checking expressions for dimensional homogeneity, or for forming nondimensional groupings for the purposes of searching for data correlations, designing model experiments, and obtaining more compact graphical representations.

Required Principles from Thermodynamics and Mechanics

The following principles and concepts constitute the basis of transfer and rate processes:

1. Conservation of mass
2. Conservation of energy
3. Dynamical equations (Newton's laws)
4. Second law of thermodynamics
5. Equations of state

The concept of irreversibility taken from the second law of thermodynamics is necessary to clarify the concept of a potential and its use in the rate equation. Newton's laws are a necessary background for the study of fluids in motion and an understanding of velocity, bulk transport and momentum transfer. Integration of the rate equations entails functional relationships derived from the principles of the conservation of mass and energy. Before these relationships are derived, the physical properties of the substances involved in the transfer processes must be known; this implies an understanding of equations of state.

Where this background information appears in the curriculum is unimportant. It is recommended, however, that thermodynamics and fluid mechanics be considered as a prerequisite for work in transfer and rate processes.

Laboratory

In order to give the student a "feel" for the magnitude of the quantities involved in transfer and rate processes as well as an appreciation of the difficulty with which the measurements of these quantities are made, some laboratory work is recommended. A useful and versatile laboratory which illustrates the principles and concepts discussed here can be devised at a relatively low cost. For example, a single pipe heat exchanger employing steam and water can be used in an effective forced-convection, heat-transfer experiment. A heated plate can be used to study natural convection heat transfer processes and radiation phenomena. Air flow past napthalene pellets and simple liquid-liquid extraction processes are useful in mass transfer experiments. The complicated situation of simultaneous heat and mass transfer processes can be easily studied in simple wet and dry bulb psychometry experiments.

It is also possible to use existing laboratory facilities and courses to illustrate the principles of transfer and rate processes. In the machinery, elec-

trical and materials laboratory, transfer and rate processes are always evident but many times ignored in the usual courses. The students' understanding and appreciation for the importance of this engineering science can be greatly enhanced by having his attention directed to a consideration of rate processes when they occur in these laboratory courses.

Example Problems

What follows is an indication of the extent to which all engineering students can profitably be exposed to the various subjects in this field of study. The specific problems cited are given only because they provide a direct and unambiguous illustration of the level of difficulty to which instruction might be carried.

The rate processes can be divided into two major categories, steady and unsteady state. Under steady state are considered those processes where the potentials (and the corresopnding rates) do not vary with passage of time.

1. *Steady-State Processes.* These processes should be considered both for one- and two-dimensional flow of heat and mass.

a. Heat Transfer

(1) One-dimensional conduction of heat through one and several resistances in series and in parallel, allowing for variations of the conductivity with temperature.

> *Typical Problem.* A flat furnace wall consists of 12 inches of refractory fire-clay brick, 5 inches of molded brick of diatomaceous earth, and ¼ inch of steel. The inside surface (refractory brick) is at 2500°F, and the outside surface of the steel is at 100°F. The thermal conductivities (k BTU ft/hr. sq. ft. °F.) are:

t°F	k fire-clay brick	k diat. earth brick	k steel
2552	1.02		
1832	0.95		
1600	—	0.18	
1112	0.85		
752	—	—	23
572	—	—	25
392	0.58	0.14	—
212	—	—	26

> Calculate the rate of heat loss through the wall, BTU/hr./sq. ft. of wall surface.

(2) Two-dimensional conduction of heat through such simple shapes as wedge-shaped bricks, radially through spheres and cylinders, and through other simple shapes.

> *Typical Problem.* A long horizontal steam pipe, 6.63 in. O.D., carries steam at a temperature of 450°F, and the outside of the pipe may be considered as being essentially at this temperature. The pipe is buried at the center of a square duct of sheet steel, 12 in. x 12 in. in cross section, with the intervening space between pipe and sheet metal filled with mineral wool (thermal conductivity = 0.04 BTU ft./hr. sq. ft. °F). The temperature of the sheet steel may be considered uniform at 80°F. Calculate the rate of heat loss, BTU/hr./ft. of pipe.

(3) Conduction-convection natural and forced, involving sensible and latent-heat transfer for single-phase fluids.

> (a) *Typical Problem.* A platinum wire, 3 in. long, 30 B. and S. gage (0.01003 in diam.) is placed in a stream of air at atmospheric pressure, 60°F, in such fashion that the air flows at right angles to the

wire. A constant voltage drop of 0.791 volts is maintained along the wire, and when steady-state conditions develop it is found that a current of 3.86 amperes flows through the wire. The resistivity of platinum is given by

$$r_t = r_{20} [1 + a (t-20)]$$

where

r_t = resistivity at t°C,
r_{20} = resistivity at 20°C = 10.6 microhms/cm.
a = 0.00369
t = temperature, °C.

Compute the velocity of the air past the wire, ft/sec.

(b) *Typical Problem.* Water is to be heated from 80° to 160°F in a 2-in., schedule 40, steel pipe by saturated steam at 218°F condensing on the outside of the pipe. The pipe is horizontal, and the water enters at an average velocity of 3 ft/sec. What length of pipe is necessary?

(4) Radiation between solids separated by a non-absorbing medium for only the simplest geometries: for example, the causes of a completely surrounded body, and two parallel planes. Within these limitations, simultaneous radiation-conduction-convective heat transfer can be included.

Typical Problem. Air is flowing steadily through a duct whose inner walls are at 500° F. A thermocouple, housed in a rusted steel well (emissivity 0.9), inserted at right angles to the air stream, indicates a temperature of 300°F. The mass velocity of the air is 3600 lb./hr. sq. ft. and the O.D. of the well is 1 in. Estimate the true temperature of the air.

b. Mass transfer may be covered to essentially the same extent as conductive and convective heat transfer.

(1) *Typical Problem.* Hydrogen gas at 2 atm. pressure, 25°C, flows through a pipe made of vulcanized neoprene rubber, whose inner and outer diameters are 1 and 2 in., respectively. The solubility of the hydrogen is 0.053 cu. cm. (S.C.) per cu. Cm. rubber per atm., and the diffusivity of the hydrogen through the rubber is 0.18×10^{-5} sq. cm./sec. Estimate the rate of loss of hydrogen by diffusion per ft. of pipe length.

(2) *Typical Problem.* Air flows parallel to the surface of a small pool of water at a velocity of 8 ft./sec. The pool is 6 in. long in the direction of the air flow. The air temperture is 80°F, and it is 50 percent saturated with water vapor. The surface temperature of the water if 68°F. For such a situation the rate of heat transfer between the gas and a plane surface is given by

$$Nu = 0.662\ Pr^{1/3}\ Re^{1/2}$$

where both Nu and Re are computed in terms of the length of the surface (6 in. in this case). Estimate the mass-transfer coefficient for this case, and the rate of evaporation of the water, lbs./hr. sq. ft.

c. Simultaneous heat- and mass-transfer processes should be covered at least to the extent that wet-bulb hygrometry for the air-water vapor system is understood.

(1) *Typical Problem.* Small water droplets (which may be con-

sidered spherical) are falling through air (80°F, 60 percent saturated) under turbulent-flow conditions. Estimate their temperature. If a drop of 3-mm diameter has a free fall velocity of 23.8 ft./sec., estimate the rate at which it is evaporating as it falls through the air described above.

(2) *Typical Problem.* Humid air is flowing through a 6-inch pipe at the rate of 25 ft./sec. average velocity. The pressure is 30 in. Hg abs., and its dry-bulb temperature is 100°F. A wet-bulb thermometer immersed in the air indicates a temperature of 85°F. Compute the rate at which water vapor is being carried by the air through the pipe.

2. *Unsteady-State Processes*

a. Heat and Mass Transfer. In conduction processes, these may be confined to problems in one-dimensional flow in solids, where contact resistance is unimportant, and in convective processes, to simple batch processes.

(1) *Typical Problem.* A large sheet of pyrex glass (thermal conductivity 0.40 BTU ft./hr. sq. ft. °F., density 155 lbs./cu. ft., heat cap. 0.20 BTU/hr. sq. ft.), 2 in. thick is initially at 300°F throughout. It is plunged into a stream of running water having a temperature of 60°F. How long will it take to cool the glass to an average temperature of 100°F?

(2) *Typical Problem.* A plank of wood 1 in. thick is dried by exposing it to relatively dry air. The thin edges are sealed, and drying takes place from the two large flat surfaces by internal diffusion of water to the surface followed by evaporation at the surface. The initial moisture content is 39.7%; the moisture content of the wood at the exposed surface remains constant at the equilibrium value for the air used at 8%, and after 7 hrs. the average moisture content is observed to have fallen to 24.0% How long will it take to dry the wood to an average moisture content of 15%?

(3) *Typical Problem.* A tank containing 200 gal. water initially at 60°F contains a steam coil immersed in the water, with 3 sq. ft. external surface. Saturated steam at 5 psig is supplied to the coil. The overall heat transfer coefficient is 80 BTU/hr. sq. ft. °F; the water is thoroughly agitated. How long will it take to bring the water to the boiling point?

b. Chemical reaction. Problems involving the determination of reaction-rate constants for 1st and second order processes from observed data, and the use of these to estimate extends of reaction for non-flow systems are suggested.

(1) *Typical Problem.* The thermal decomposition of dimethyl-ether according to the reaction

$$(CH_3)_20 \; CH_4 + H_2 + CO$$

in the base phase at 504°C, 312 mm. Hg initial pressure, provided the following data:

time, sec.	390	777	1195	3155
Total pres., mm Hg.	408	488	562	779 931

Determine the rate constant.

(2) *Typical Problem.* In every gram of radium, 13 x 10^{10} atoms change per sec. into radium emanation. How long does it take for ⅓ the radium to disappear? The Avagadro number is 6.06 x 10^{27}, and the at. wt. of radium = 226.

Note: The first-order processes might well be expanded to include simple, first-order mixing calculations, as per the following (Hitchcock and Robinson, p. 25, no. 22): A factory room 200 x 45 x 12 ft. received through the ventilators 10,000 cu. ft. fresh air/min., which contains 0.04% CO_2 by volume. The help enters at 7:00 A.M., and ¾ hr. later the CO_2 content has risen to 0.12% CO_2. What value is to be anticipated at noon? How much fresh air must be admitted per min. to ensure that the CO_2 shall never rise above 0.10%? Assume complete mixing of fresh air and the air in the room.

DISCUSSION OF OUTLINE

The "transfer and rate processes" constitute a relatively new organization of knowledge, the concepts of which are somewhat unfamiliar. The following discussion is offered in order to emphasize and to spotlight the coordinating principles around which this engineering science is organized.

Definition of Rate Processes

All rate processes of engineering may be described by definitions which incorporate elements analogous to those in the definition of velocity:

1. An element involving the time rate of change of a property.
2. A description of the system indicating a direction of change and a description of how the change might be measured.

Movement of Transfer of Mass.

Engineers are concerned with two consequences of the transfer of mass:

1. The bulk transport of material from one position to another: a phenomenon not necessarily involving a change in composition.
2. The movement of one or more components within or between phases:—a phenomenon which produces composition changes without necessarily producing a change in the position of the system as a whole.

The pumping of a fluid from one tank to another through a pipe illustrates the first type of mass transfer whereas the solution of salt crystals in a tank of water illustrates the second type.

In order to avoid confusion, the first type is referred to as "Bulk Transport" and the second as "Mass Transfer."

Bulk Transport. The rate of bulk transport is basically a velocity. With fluid flowing in conduits, it is often called mass velocity with the units mass per unit time per unit area normal to flow.

With fluid flowing in a pipe, the resisting forces are exerted by the pipe wall on the fluid and must be balanced by other forces such as a pressure gradient through the fluid. Here, momentum transfer may be regarded to occur within the fluid and at the pipe wall. An analysis of the momentum transfer exerted in bulk transport helps in understanding not only the fluid flow systems, but also the relationships which describe the transfer of energy and mass in fluid systems.

Mass Transfer. The relative movement of components within a phase is called mass transfer. Mass transfer processes produce composition changes or composition gradients. An example is afforded by a tank of liquid into which a batch of crystals is charged. The rate of solution of the crystals is the rate of mass transfer from the solid phase into the liquid phase expressible as pounds per hour. It is convenient to express the rate of mass transfer in terms of a unit system. In the present example, as in most mass transfer operations involving two phases, the only definite dimension descriptive of the system is the interfacial area or crystal surface so that

$$r = \frac{-1}{A}\frac{dW}{d\theta}, \qquad (1)$$

where

r = mass transfer rate
A = area of crystals at time θ
W = mass of crystals at time θ
θ = time

Chemical Reaction. Chemical reactions are detected through the analysis of a reacting mixture at different times which show a change in the mass of a particular chemical species present. In defining the rate of change, it is necessary to identify the species in the definition and it is convenient to incorporate a unit extent of the reacting system. Thus, the rate of the reaction

$$CO + \tfrac{1}{2}\,O_2 = CO_2 \qquad (2)$$

could be definied by

$$r = \frac{-1}{V_r}\frac{d(CO)}{d\theta} \qquad (3)$$

or

$$r = \frac{-1}{V_r}\frac{d(O_2)}{d\theta} \qquad (4)$$

or

$$r = \frac{1}{V_r}\frac{d(CO_2)}{d\theta} \qquad (5)$$

where

r = reaction rate
θ = time
V_r = volume of the reacting system
(CO), (O_2), (CO_2) = moles of carbon monoxide, oxygen, or carbon dioxide present at time, θ.

Heat Transfer. Consider a tank of liquid being heated by steam condensing in a heating coil. The liquid is thoroughly agitated so that the liquid in the tank may be considered to have a uniform temperature at any particular time. Also assume that the heating coil is of sufficient diameter to drain off steam condensate rapidly and to offer little resistance to the flow of steam so that the steam is condensing at a uniform temperature.

The rate of heat transfer may be defined as the total BTU's per hour which are passing from the steam to the liquid through the heating coil. It is convenient to define the rate in terms of a unit dimension of the system, in this case, per square foot of area normal to the direction of heat transfer. There are several areas which are normal to the direction of heat transfer, namely the inside area of the coil, the outside area of the coil (length x circumference) or an average of the two. Any one of the relevant areas may be used in a definition of the rate so that for example

Rate = BTU/(hr.) (sq. ft. outside area)

For a differential increment of time an enthalpy balance, either for the steam or the liquid, gives

$$r = \frac{dQ}{A\,d\theta} = \frac{WC_p\,dT}{A\,d\theta} = \frac{\triangle H_s}{A}\left(\frac{dw}{d\theta}\right) \qquad (6)$$

W = mass of liquid being heated
C_p = heat capacity
Q = heat which has been transferred to the fluid at time θ
θ = time

ΔH_s = enthalpy difference between steam and condensate
w = Condensate at time θ
A = area normal to the direction of heat transfer

Process Calculations

A primary objective of an engineer's efforts is to determine the size of the equipment needed in order to accomplish a desired change. In a batch process, the relationship required for sizing equipment is that between time and the extent of the change. In continuous process the relationship required is that between size and the extent of the change. However, in continuous processes, the size of the equipment is equivalent to a time variable. Almost all calculations directed towards sizing equipment are equivalent to a rearrangement and integration of the mathematical definition of the rate of change involved.

Variable Time (Batch) Processes. The foregoing discussion may be summarized by saying that a rate process may be defined by

$$r = \frac{1}{A}\,\frac{d\tau}{d\theta} \qquad (7)$$

where

r = rate of change of the property
θ = time
τ = property
A = extent of the system

The relation between the property undergoing change and time, which is the objective of process calculations, is obtained by the integration of the rate definition.

$$\theta_2 - \theta_1 = \int_{\theta_1}^{\theta_2} d\theta = \int_1^2 \frac{1}{A}\,\frac{d\tau}{r} \qquad (8)$$

$$\tau_2 - \tau_1 = \int_1^2 d\tau = \int_{\theta_1}^{\theta_2} ard\theta \qquad (9)$$

The basic information required to perform the integration is the relation between the rate, r, and either the property undergoing change, τ, or time θ.

Continuous Processes. In continuous operations, when the rate is defined as the rate of change of a property per unit time per unit area, or volume element of the system,

$$r = \frac{1}{V}\left(\frac{d\tau}{d\theta}\right) \qquad (10)$$

Then the rate of change of the property of material flowing through element dV is

$$r\,dV = \text{rate of change of } \tau$$

The rate of change of τ can also be calculated from an energy of material balance, which may be written symbolically as

$$d\,(L\delta)$$

Then the relation between the size of the equipment and the property undergoing change is given by

$$V = \int_0^V dV = \int \frac{d\,(L\delta)}{r} \qquad (11)$$

The Rate Equation and Associated Concepts of Potential and Resistances

All of the process calculations require the relationship between rate and the environment in which the process occurs. This requirement and the definition of rate lead to a logical means of measuring the rate and defining the environment in which the rate occurred by determining quantitatively the significant properties of the environment.

The Rate Coefficient. Experience with rate processes of all kinds has indicated that one convenient way to formulate relationships between the rate and its environment is to attempt to separate the so-called potential factors which "drive" rate processes from the "resistance factors" which tend to oppose the rate processes. The separation of potential factors from resistance factors may be expressed by the relation

$$\begin{aligned}\text{Rate} &= (\text{Potential Factor})/(\text{Resistance}) \\ &= (\text{Potential Factor})(\text{Conductance}) \end{aligned} \quad (12)$$

It should be emphasized that this is an arbitrary statement made in the hope that the resistance or conductance will not include or depend upon variables which enter the potential term.

Potential Factors. The basis of separating potential factors lies in the second law of thermodynamics which in one form can be stated "all systems tend to move toward a state of equilibrium." It should be noted that an equilibrium state is one in which the rate of a process is zero.

The potential factors may be defined as those which are in balance at equilibrium when there is no flow of energy or mass. It is reasonable to suppose that the rate of a process will be faster, the further the system is from equilibrium. One measure of the distance a system is from equilibrium is the difference between the factors that are in balance at equilibrium. It is then hoped that the rate is directly proportional to this difference, although the experimental facts do not always accomodate this hope and may require a more complicated correlation.

Bulk Transport of Material. The potential factor which produces a bulk transport of material is a force. If no force is available to overcome resistance to movement, no movement will occur. In the transport of fluids, the force tending to move the fluid is ordinarily a pressure gradient or pressure difference, and the fluid tends to move in the direction of the gradient, i.e., toward decreasing pressure.

In correlating the rate of flow of fluids, it is possible to use an Ohm's law concept by writing

$$r = \beta \frac{(-dP)}{dL} = \beta' \left[P_1 - P_2\right] \quad (13)$$

where

$\frac{-dP}{dL}$ is the pressure gradient in the direction of flow

r is the rate of flow, expressed either as mass velocity or linear velocity.

When the pressure variable is separated in this manner, the term, β, turns out to be a function of the flow rate, so that the correlation is only partially successful. It is, however, quite usable and some fluid-flow correlations employ a form of (13) and an additional correlation of β or β' with the properties of the fluid and its rate of flow.

Mass Transfer. A phase is in equilibrium with respect to mass transfer when its composition is uniform. When composition differences exist in the phase, a transfer of mass occurs which tends to eliminate the differences.

When it is convenient (it rarely is) to measure composition at various positions in a phase, the rate of mass transfer may be correlated by assuming that it is proportional to the concentration gradient or its equivalent. Thus

$$r = -k\frac{\partial c}{\partial L} \quad (14)$$

where

c = concentration of a given component
L = distance
r = rate of mass transfer

When equation (14) describes the

data with the conductance term, k, as a constant, independent of concentration or rate, we have a "successful" correlation. Mass transfer, which is described by equation (14), is often called "diffusion." The amount of such data which is now available is quite small and often of rather poor quality, so that it is difficult to say how important equation (14) is. By analogy to the description of chemical equilibrium in thermodynamics, one might suspect that equation (14), using "activity" or "fugacity," would be a more broadly applicable correlation tool but the present data available do not justify such refinement for their correlation.

More often, composition data are not available at different points in a system. In such cases, correlation of the rate of mass transfer is attempted by assuming that it is proportional to the difference between the average fugacities in the two streams. A concentration in a liquid phase, thus,

$$r = \bar{k} (f_1 - f_2) \qquad (15)$$

Equation (15) has been successful in describing mass transfer in systems involving fluids in turbulent flow.

Transfer of Heat. A system is at thermal equilibrium when its temperature is uniform. When its temperature is not uniform, temperature differences must exist in the system, and a flow of heat occurs in the direction of decreasing temperature.

When it is convenient to measure temperature at various geometric positions of a system, it is assumed that the rate of heat flow is proportional to the temperature gradient. Then

$$r = \alpha \left(-\frac{\partial T}{\partial L}\right) \qquad (16)$$

where

$-\frac{\partial T}{\partial L}$ = the temperature gradient in the direction L

r = rate of heat transfer in the the direction L

α = proportionality constant

When (16) "satisfactorily" correlates the data, the proportionality constant, α, is insensitive to temperature and position and the phenomenon is called, "conduction." Equation (16) is successful in correlating a great deal of data on heat transfer through solid materials and is sometimes called the Fourier law for thermal conduction.

In many cases, it is not convenient experimentally to measure temperature at various positions in a system. For example, in a double pipe heat exchanger, it is not feasible to measure temperature at various radii of the inner pipe and annulus when filled with flowing fluid. Ordinarily, it is convenient to determine only the mixed average temperature of the fluid in flow. Of course, this must be done in order to determine its enthalpy. By mixed average temperature, is meant the temperature which the fluid would come to if removed to an insulated pot and thoroughly agitated.

Where temperature is not measured as a function of position, the rate of heat transfer is correlated by assuming that it is proportional to the difference in temperature between two points in the system between which heat is being transferred, i.e.

$$r = U[T - t] \qquad (17)$$

In the case of the double-pipe heat exchanger, T might be the mixed average temperature of the fluid in the inner pipe and t the mixed average temperature of fluid in the annulus. Expressions such as (17) have proved successful in separating the potential factors of temperature in many heat transfer processes involving fluids in turbulent flow.

On the other hand, equation (17) is not particularly successful in correlating

the rate of heat transfer by radiation, which is better described by

$$r = u\,[T^4 - t^4] \qquad (18)$$

Thus, if equation (17) were used to describe radiant heat transfer, the temperature would have an important effect on the conductance, u.

Chemical Reactions. For chemical reactions such as

$$A + B = C + D \qquad (19)$$

equilibrium is expressed by the balance of fugacities, such that

$$f_A f_B = \frac{f_C \bullet f_D}{K} \qquad (20)$$

The distance from equilibrium may then be expressed by

$$f_A f_B - \frac{f_C f_D}{K} \text{ or by } K f_A f_B - f_C f_D \qquad (21)$$

Thus the rate of reaction may be expressed by

$$r = k\left[f_A f_B - \frac{f_C f_D}{K}\right] \qquad (22)$$

Most simple chemical reactions which have been studied in any detail are well correlated by (22), which is to say that when the reaction rate is divided by a suitable driving force such as

$$\left[f_A f_B - \frac{f_C f_D}{K}\right],$$

the conductance, k, is not a function of composition.

The general approach to the correlation of rate processes is, then, first to select the potential factors which thermodynamics requires to be in balance at equilibrium, and second, to formulate a driving force, usually a relatively simple function of the potential factors which, when divided into the rate, yield conductances or resistances which are independent or insensitive to both the rate and the driving force itself. The resistances so determined are then related to the physical properties of the system.

Summary

The rate equation provides the uniqueness for the subject of transfer processes, just as Hooke's law provides the uniqueness for the subject of elastic body mechanics. Like the Hooke law combination with Newton's laws in the field of elasticity, a rate equation combines with a conservation-of-energy relation for heat transfer, a conservation-of-matter relation for mass transfer, and a resultant-force-rate-of-creation-of-momentum relation (from Newton's second law) for the transport of momentum.

It is well to emhpasize the basically empirical nature of the various rate equations and the strong influence that technical convenience and convention have in its formulation. It is also important to associate the rate processes more closely with the second law of thermodynamics by evaluating the rates of creation of entropy connected with each of the transfer processes or, alternatively, the loss of available energy.

Just as the subject matter of elasticity integrates strongly with solid-body mechanics, the treatment of rate processes can and should be integrated with fluid mechanics and thermodynamics. Avoidance of this intergration would be tantamount to the omission of much of the science of the subject.

THERMODYNAMICS

COMMITTEE:
N. A. Hall, Chairman
J. J. Martin
E. F. Obert
D. V. Ragone
F. D. Rossini
F. W. Sears
Myron Tribus

INTRODUCTION

Thermodynamics[1] is the science devoted to the study of energy, its transformations and its relation to status of matter. Since every engineering operation involves an interaction between energy and materials, the principles of thermodynamics can be found, in whole or in part in all engineering activities. Thermodynamics is fundamental to the study of the properties of matter and therefore is essential to the understanding of the processes of metallurgy, chemical engineering and engineering materials. Thermodynamic laws govern the production or utilization of heat and all forms of work.

This report is concerned with the common fundamental laws, concepts, modes of analysis and skills which underlie all applications of thermodynamics in engineering. It is not concerned with the methods used to combine these fundamentals in a course or group of courses.

It is not expected that this material should serve as an outline for any course or sequence of courses, nor should it be implied that this content should represent any absolute minimum. An attempt, however, has been made to list the common core of thermodynamic information and to emphasize those features of the material which should be stressed.

THERMODYNAMIC TRANSFORMATIONS

Thermodynamics gives information regarding both processes in which transformations occur and states of equilibrium. The domain with regard to transformations is suggested schematically by the array in Figure 1. Each box in the array represents a device or process which involves a transformation of energy preceding from the input at the left to the output at the top. Devices which ultimately transform energy back into its original form are "transmission" systems and occur, as indicated, along the diagonal. The various other devices shown illustrate the broad scope of thermodynamics. This listing is not intended to be exhaustive in any sense but rather indicative and suggestive.[2] It is significant that for each of the energy transformations indicated in Figure 1, some

[1] (When the microscopic view of matter is pursued the field is called "Statistical Thermodynamics"; when the view is macroscopic the science is called "Thermodynamics" or "Classical Thermodynamics".)

[2] It is not intended to presume that every transformation indicated should be covered in a course labeled "Thermodynamics." Historically, energy methods of analysis originated in mechanics and students normally first learn the methods there. Where the students learn to reason about energy balances for the systems of Figure 1 is unimportant. What is important is that the complete generality of the thermodynamic principles is made clear and that students do not gain the idea that thermodynamics pertains only to heat-power or to chemistry.

deductions may be made from the fundamental principles of thermodynamics. It is recognized that a full understanding of certain processes will require additional principles and that these cases may be considered in specialized courses or even a series of courses. Nevertheless, the methods of applying thermodynamics are common to all cases and should be so developed.

The transfer and transformation of energy indicated in Figure 1 are summarized quantitatively by the principle of conservation of energy. This principle may be stated in the form:

$$dE = dQ - dW + \Sigma_i(e_i + p_i v_i)\ dm_i$$

The differentials in this equation refer specifically to increments pertaining to a certain process being followed by the system. Those on the right, involving heat, work, and mass, are inexact and depend on the path of the state change. That on the left involves a property of the system and is exact. The distinction between these two types of differentials is fundamental. In addition,

E = energy content equal to the sum of internal, kinetic, and potential energies

e_i = specific energy of i'th component at its point of transfer

v_i = specific volume of i'th component at its point of transfer

m_i = mass of i'th component being transferred

P_i = pressure at the point of transfer of the i'th component

Q = Heat

W = Work

THERMODYNAMICS INSTRUCTION

The objectives of instruction in engineering thermodynamics are:

1. To introduce the student to the fundamental concepts, laws and properties.
2. To develop skills in the thermodynamic mode of reasoning.

Traditionally, engineering teachers have stressed a logical order of procedure in applying first the concepts and then the laws of thermodynamics. Thermodynamic reasoning is deductive in character rather than inductive. The reasoning is always from the general law to the specific case.

The thermodynamic mode of analysis is somewhat different from the modes of analysis used in some other engineering sciences (which start from concepts of circuits, fields, particles, etc.), but has in common with them certain characteristics of engineering analysis.

To illustrate the elements of themodynamic reasoning which are similar to other ways of reasoning and those which are different, the analytical processes may be arbitrarily divided into two steps.

1. The first step is the idealization or substitution of an analytical model for a real system. This step is taken in all engineering sciences. For example, in analysis of a truss bridge the structural members are taken as though they were inflexible, the joints as pin joints, and the loads as concentrated, etc. In the thermodynamic analysis of the filling of a pressure vessel one often treats the gas as perfect, the walls as insulated and so on. These idealizations are fairly easy to make after a little experience. Skill in making them is an essential part of the engineering art.
2. The second step, unique to thermodynamics,[3] is the deductive reasoning from the First and Second Laws of thermodynamics. There are several usual steps in this analysis as follows:

[3]Other fields have their unique methods of analysis; i.e. the "free-body diagrams" of strength of materials. These form the tools the science of astronomy is the basis of the essential for application of the principles.

1. Precise definition of the boundaries of the system.
2. Identification of the terms in the general energy equation.
3. Reduction in number of variables through use of property relations.
4. Identification of entropy changes resulting from heat and mass transport as well as from irreversibilities.

These steps will involve: (a) An energy balance, (b) A suitable properties relation, and (c) An accounting of entropy changes.

Skill in the thermodynamic mode of analysis implies an ability to apply these techniques to unfamiliar systems occurring in any of the squares in Figure 1.

Fundamental Principles and Concepts

The fundamental principles of thermodynamics are:

0. The Zeroth Law introduces the concept of temperature and establishes the conditions for its constancy or equality between different bodies of matter.
1. The First Law establishes the concept of energy and relates the change of energy in a system to the transfers of energy between the system and surroundings.
2. The Second Law observes that all processes which do take place will not spontaneously reverse themselves, and establishes entropy as a property.
3. The Third Law introduces the concept of absolute entropy.

The application of the four Thermodynamic Laws requires certain elementary concepts. Among these are:

1. The concept of a system, its precise boundaries and its pertinent surroundings.
2. The concept of the equilibrium state of matter.
3. The concept of thermodynamic macroscopic properties which both determine and/or are determined by the state of matter.
4. The concept of irreversible and reversible processes.
5. The concept of mass and energy transfers across the boundaries of a system during a process.

Instruction in thermodynamics should cover both the fixed mass (closed) system and the variable mass (open) system, so that energy and entropy relations may be of complete generality.

An accounting of the factors contributing to the change in entropy of a system as implied by the Second Law may be stated quantitatively in the most general case by the relation

$$dS = d\left(\frac{Q}{T}\right) + \Sigma_i \; s_i \; dm_i + dI$$

The differential on the left is exact and depends only on the change in state of the system. The differentials on the right are inexact and depend on the path of the state of change. The first differential on the right involves the quantity

$$\frac{Q}{T} = \Sigma_k \frac{Q_k}{T_k}$$

This summation extends over the points on the system boundary where quantities of heat, Q_k, are being transferred at temperature, T_k. The last differential is frequently replaced by an inequality in view of the Second Law condition that

$$dI \leq 0$$

The quantities occurring are:

S = Entropy

S_i = Specific entropy of i'th component at its point of transfer

m_i = Mass of i'th component being transferred

Q_k = Quantity of heat transferred at boundary position with temperature, T_k

T_k = Temperature at boundary position

I = Irreversibility (variously expressed in terms of entropy production, energy dissipation, lost work, kinetic energy conversion, decrease in availability, etc.)

When thermodynamic properties are introduced they should be clearly separated into those which are intensive (pressure, temperature and chemical potential) and those which are extensive (energy, entropy and volume). The distinction between these latter properties and specific properties (i.e., extensive properties per unit mass or per mol) should be explained.

The most general form of the properties equation is

$$dU = TdS - PdV + \Sigma_i \mu_i dm_i + \Sigma_k F_k dX_k$$

where

U = Internal energy
T = Temperature
S = Entropy
p = Pressure
V = Volume
μ_i = Chemical potential
m_i = Amount of i'th component
F_k = Generalized force
X_k = Generalized displacement

The last term in the above equation represents means for producing reversible work effects other than by volume changes. The following are a few examples of the generalized forces and displacements:

Work	F_k	X_k
Elastic	Stress	Strain
Magnetic	Magnetic Intensity	Magnetization
Electric	Potential	Charge
Surface	Surface Tension	Area

Whenever the temperature, pressure, chemical potential and generalized forces can be unambiguously defined, this equation may be used. Its use is not restricted to equilibrium processes or states.

Thermodynamic Equilibrium

The several basic relations of thermodynamics have a primary application in the determination of equilibrium configurations of systems in addition to their use in the analysis of processes. The properties relation is particularly useful in this regard. Directly dependent on it is the analysis of phase equilibrium of pure substances and of mixtures. Also, when this relation is associated with the chemical balance equation, the equilibrium composition of chemically reacting systems may be determined. A substantial portion of the structure of thermodynamics is derived from the equilibrium problem. Many properties such as free energy, fugacity, chemical potential, activity, and heats of formation and phase change, have their major use in this area. This aspect of the general fields has been generally restricted to the subject of chemical thermodynamics. This limitation, however, is unduly severe, and some foundation in the equilibrium analysis of multicomponent and of polyphase systems is desirable in all cases.

The Role of the Microscopic View

Engineering thermodynamics has traditionally dealt with the macroscopic view of the matter. Developments in solid-state physics and modern physics are making possible many advances which can only be exploited if one understands the microscopic view. Although the laws of thermodynamics are in no way dependent on the microscopic view of matter, it serves to unify the student's view of science if the elementary notions of statistical mechanics are introduced at various points in the instruction. The statistical interpretation of entropy and the Boltzman distribution of law are therefore desirable additions to the subject.

The Thermodynamic Properties of Materials

Applications in thermodynamics require knowledge of properties of materials; thermodynamics permits one to show how these properties must be related. This support of and dependence upon knowledge of material properties can be understood if certain concepts and factual data are presented to students. The following outline presents the information and characteristics which are of general consequence. The various items of factual data are available in the form of tables, charts and other numerical arrangements. It is desirable that the student become familiar with the availability and use of various sources for such data.

1. State Phenomena
   a. The concept of phase
   b. Phase boundaries
   c. Critical point
   d. Triple point
   e. Phase transitions for mixtures
   f. Nonmechanical work effects
2. Equations of State, P-V-T Relations, Phase Relations
   a. Perfect gases
   b. Imperfect gases
      (1) Semitheoretical equations such as Van der Waals
      (2) Principal of corresponding states
   c. Liquids and gases
   d. Phase boundary equations; Clausius-Clapeyron equation
   e. Phase relations for mixtures, phase equilibrium constant
3. Energy Functions
   a. Heat capacity
   b. Internal energy, enthalpy, entropy, and free energy of pure substances
      (1) Perfect gases and temperature functions
      (2) Imperfect gases and liquids, tables, correction terms
   c. Mixtures; ideal and nonideal solutions
      (1) Phase diagrams
      (2) Partial molal values, chemical potential, activity coefficients
   d. Chemical reactions: absolute entropies, enthalpies and free energies of formation and reaction
   e. Equilibrium constants

Interpretive Illustrations

The following examples are included in order to amplify the general remarks and to associate them with selected specific situations. These are not intended to be exhaustive, nor should any particular significance be attached to the selection made. It would be expected that a thorough course in engineering thermodynamics would include topics of this level and consequence.

1. As illustrations of the concept of boundary, work, internal energy, discuss such familiar devices as closed refrigerators in transient or steady state, food mixers, electric drills, electric heaters, automobile brakes, tire pumps, etc. Show how, by relocating boundaries, heat effects take on different meanings.

2. Simple steady-flow devices, such as combustion chambers or other steady-flow systems utilizing chemical changes may be used to illustrate the notion of the energy balance for a region of space. Nozzles and hydroelectric systems are also good examples.

3. The various forms of energy balance may be presented, demonstrating the special forms assumed for open and closed systems, for transient and steady-state processes, and for single and multicomponent media. Specific illustrations may be drawn from such cases as a) Simple intake stroke in a piston-cylinder device; b) Escape of gases from a rocket; c) Throttling of steam or other "imperfect" gas; d) Constant volume reactions as in a bomb calorimeter.

4. The Second Law may be illustrated with reference to non-isentropic processes in general by indicating the distinctions between entropy changes resulting from heat transfers with respect to the system and those resulting from irreversibility expressible in terms of the so-called "entropy production." Using the concept of availability, this distinction can also be developed.

5. In an initial approach to themodynamics, statistical concepts, as related both to energy and entropy, can be introduced as an heuristic manner that establishes the concepts, but does not aim towards rigor. The relation of entropy to probability statistics can be shown, for example, in the case of mixing entropy. The relation between statistics and entropy can be indicated by the case of the internal energy of a harmonic oscillator and correlated with the specific heat variation of a diatomic molecule such as nitrogen.

6. In addition to the systematic direct use of tables of properties such as steam and refrigerant tables, more fundamental understanding will result from checking the tables for internal consistency by use, for example, of the Maxwell partial derivative relations.

7. Sequences of thermodynamic processes such as occur in cycles may also be extended to include complex noncyclic sequences such as the manufacture of dry ice or supercharged combustion in a steam power plant.

8. The diverse applications of thermodynamics can be demonstrated by introducing nonmechanical work as in magnetic refrigeration or the electrical work done on a dielectric in charging a capacitator.

9. The relation of thermodynamics to nuclear energy need not be restricted to the abstract inclusion of a reactor as a heat source. It is possible to give a preliminary examination of the nuclear reaction itself as a thermodynamic process in which a transformation takes place between one form of energy content and another. Furthermore, the mass-energy relation of nuclear physics can be tied in profitably with the conservation principles of thermodynamics.

DEVELOPMENTS IN ENGINEERING THERMODYNAMICS INSTRUCTION

Webster puts the matter succinctly: "A science teaches us to know; an art to do so."[4] As the problems engineers face increase in complexity and diversity it becomes less and less satisfactory for an engineer to have learned only the arts developed by his predecessors. New arts are developed so rapidly and old ones made obsolete so quickly that only those trained in the sciences can expect to keep pace with the changing demands.

At the beginning of World War II there existed a great disparity between what was taught as "Thermodynamics" by Josiah Willard Gibbs in 1878, Max Planck in 1917 or Lewis and Randall in 1922.

The engineering courses were more concerned with the art of application to specific systems even, if necessary, at the expense of an understanding of fundamentals.

More than one engineering text contained the admonition that the student should "not seek to understand entropy but merely to use it."

The trend is toward thermodynamics instruction which emphasizes the fundamentals and uses the applications merely as illustrations. There appears to be a healthy attempt to keep engineers abreast of the scientific developments in

[4] "The sciences are the basis of the arts; the science of astronomy is the basis of the art of navigation."

thermodynamics. Textbooks written for engineers now contain references to the latest topics in science such as "irreversible thermodynamics," "entropy of communication" and other developments of comparatively recent origin. It seems self-evident that the future will reveal an even stronger trend in this direction and that the requirement that an engineer be broadly trained will force a continued emphasis on teaching only the fundamentals; i.e., the "time invariant" information. It is believed that such a broad training is possible and fruitful because, as one member of our committee has stated it, "What needs to be emphasized in thermodynamics more than almost anything else is that the towering structure of literally hundreds of mathematical relations has at its foundation just three basic equations—energy, entropy and properties."

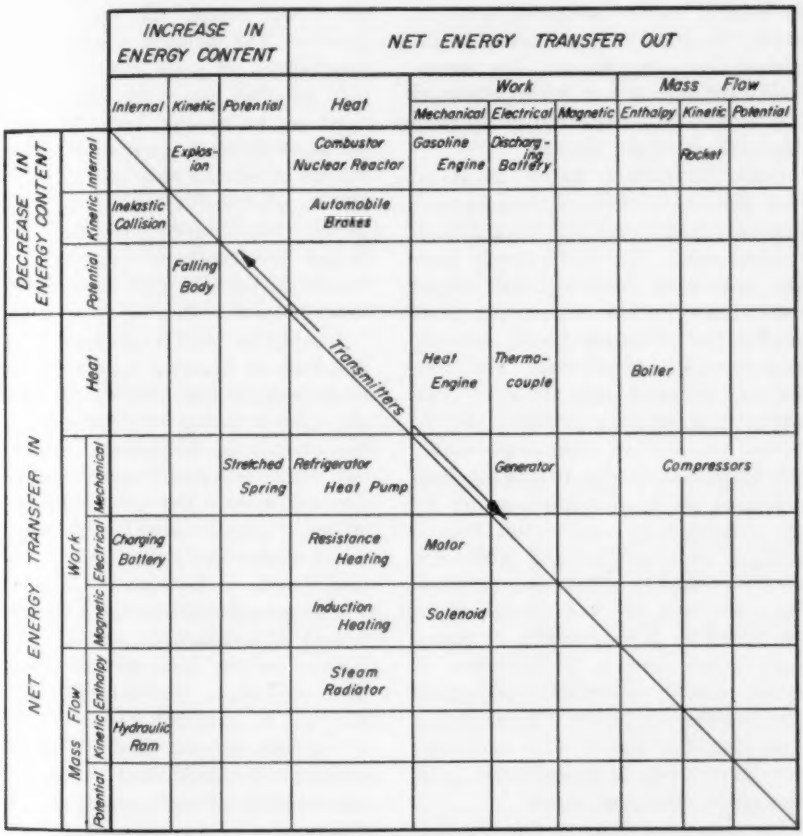


FIGURE 1. THE DOMAIN OF THERMODYNAMICS TRANSFORMATIONS

The devices indicated are illustrative only. Many others are of substantial importance. Each square represents a particular type of thermodynamic transformation.

ELECTRICAL SCIENCES

COMMITTEE:
T. L. Martin, Chairman
R. E. Beam
G. S. Brown
E. G. Smith
P. H. Weinberg

INTRODUCTION

This committee was directed to define the subject matter associated with the words "electrical science" used in the original Evaluation Report. The responsibility for such a task is overwhelming in a subject area characterized by such rapid and continual change.

Once the subject matter associated with electrical science is summarized, then an equally vital and more difficult problem arises. This is the purely practical matter of resolving the subject material into courses with rather exact specification of credit hours, breadth, depth, emphasis, omissions, and connections to other subject areas. This activity can only be regarded as the special province of true responsibility and obligation of the faculty at each individual institution. Any attempt by any committee to assume this responsibility is presumptuous and could only serve to restrict educational progress. Thus, we hope that our report will be interpreted as a specification of future goals, rather than as a delineation of course content immediately acceptable to engineering educators. It is our further hope that this report will encourage more rapid progress toward these goals than might otherwise occur.

The committee believes that the "EE service course" found in many engineering curricula is not a course in electrical science as we understand it. This should be clear from an examination of the main body of the report. We recognize that some readers will hope to find an outline here for a new "science oriented EE service course." They will be disappointed. The dangers inherent in the specification of some *minimum* acceptable program are so obvious that they need not be restated here. Whether or not any institution incorporates electrical science as defined here into its program for nonelectrical engineers is a completely local institutional matter controlled by academic philosophy and standards, together with faculty inclinations and capabilities.

Readers may find it significant that our definition of electrical sciences proceeds in both depth and breadth. As a result the subject matter very often overlaps that covered in other reports, particularly the report on properties of materials. Depending upon the viewpoint adopted at each school, other major overlaps with mechanics and thermodynamics may result.

The general attitude of the committee is best summarized by saying that adherence to the spirit of the report is most important; the definition of the program in electrical sciences in terms of specific courses, credit hours, and coverage in breadth and depth, is the responsibility of each educational institution.

Finally, we wish to call attention to what we consider to be a serious defect in the entire effort of the *ad hoc* committee. We believe that the resolution of engineering science into the six subject areas specified in the original evalu-

ation report creates a fundamental anomaly which cannot be ignored. This situation is created by placing subjects such as materials and electrical science side-by-side with subjects such as thermodynamics, applied mechanics, and the like. We believe that these represent wholly different classes of material and that it is unrealistic to place them in positions of comparable importance.

For example, electrical science and the science of materials are each subjects fully as large as mechanical or civil engineering, or any other established engineering field. In contrast, thermodynamics, applied mechanics, and the like are merely components of nearly equal weight in, say, mechanical engineering. If electrical science were treated this way it would be reduced into several components such as circuit theory, field theory, and signal processing, with each part having an importance comparable to thermodynamics and applied mechanics.

Readers who fail to recognize and appreciate this anomaly will be misled rather seriously by the reports of the various *ad hoc* task groups.

STATEMENT OF PRINCIPLES

The objective of an engineering curriculum is to lay a firm foundation for the understanding of matter, energy, and information directed toward their creative exploitation in existing and future organized systems of man and environment. It is understood that environment has both physical and cultural aspects.

The program in electrical science contributes toward the achievement of this curricular objective by treating the phenomena of electric charge carriers, their associated fields, and their interactions with matter. The dominant manifestations of these phenomena are in two general areas denoted as *energy processing* and *information processing*. The subject matter associated with each of these major topics is outlined in the sections that follow.

Energy Processing

I. Basic Concepts of Electromagnetism

A. Interactions of Charges and Fields in vacuum

1. Phenomena associated with stationary charges, to include fields of force, gradient, work and potential, and Gauss's law.
2. Phenomena associated with moving charges, to include Amperian currents, magnetic field, magnetic potential Ampere's law, force on current elements.
3. Phenomena associated with accelerated charges, to include Faraday's law, conservation of charge, displacement current, Maxwell's equations, power and energy considerations.

B. Interactions of Charges and Fields in Matter

1. Electric and magnetic polarization permittivity, permeability, susceptibility
2. Electric and magnetic hysteresis
3. Conductivity in all states of matter, metals, semiconductors, insulators, liquids, gases

C. Environmental Factors

1. Temperature, to include Curie phenomena, superconductivity, work function, lattice energy, ionization phenomena
2. Strain, to include magnetostriction, piezoelectric phenomena
3. Irradiation

D. Circuit Concepts (to include development from energy considerations and applications of concepts to development of circuit theory)

II. Basic Concepts of Energy Processing
- A. Energy Storage
  1. Capacitance
  2. Inductance
  3. Nuclear
  4. Chemical (to include fossil fuels)
  5. Inertial, and so on
- B. Energy Conversion
  1. Electromechanical, electroacoustical
  2. Thero-electric
  3. Electro-electric
  4. Radiation and its consequences
  5. Electro-chemical
  6. Mass-energy
- C. Control of Energy
  1. Signal identification
  2. Switching
  3. Amplification
  4. Feedback
- D. Transmission and Radiation of Electrical Energy
  1. Conduction
  2. Convection
  3. Diffusion
  4. Displacement
  5. Radiation

Information Processing

I. The Problem Areas
- A. Information Transfer or Communication (in space or time, or both)
  1. Communication from man-to-man where there is no alteration of language or logic
  2. Communication from machine-to-machine of common logic patterns
  3. Alterations in logic process as in communication from man-to-machine and machine-to-man

II. The Definitive Aspect of Information
- A. Sources, Perceptors, Transducers (Most of the physical phenomena associated with these topics are covered in Energy Processing)
- B. Identification of Information Consideration of noise, redundancy, bandwidth, channel capacity
- C. Effects of feedback

III. Information Processing
- A. Transmission in Space
  1. Electrical media and processes such as waveguides, transmission lines; propagation in ionosphere, troposphere, free space
  2. Mechanical and acoustical media; gaseous, liquid and solid
- B. Transmission in Time (Storage)
  1. Magnetic and dielectric phenomena
  2. Conductive and superconductive phenomena
  3. Relationship to Properties of Materials
- C. Coding and Related Processes
  1. Carrier modulation
  2. Pulse modulation
  3. Sampling techniques
  4. Coding, continuous and discontinuous
  5. Multiplexing in the time and frequency domains
- D. Operations
  1. Logical operations
  2. Mathematical operations
  3. Comparisons
  4. Decision-making

(The subjects of electronics and electronic circuits, which lead to the development of equipment to perform the functions listed above, are properly listed under Engineering Analysis and Design.)

SUGGESTIONS CONCERNING IMPLEMENTATION

The question of mathematical support will arise at the very outset. The committee suggests that curriculum planners give serious thought to the possibility of including the following subjects:

1. Differential equations
2. Statistics and probability theory
3. Vector analysis
4. Some aspects of complex variable theory

The breadth and depth of the program that results will depend to a large extent upon the fraction of this subject matter actually required.

In treating the environmental factors affecting the interactions of charges and fields with matter, curriculum planners should carefully review the report of the Committee on Nature and Properties of Materials.

It is suggested that the subject of electrical science be analyzed without regard to artificial distinctions imposed by words such as "basic science" and "engineering science." There is no dividing line. Thus, the subject matter listed in the report may appropriately be covered in either physics or engineering courses or both.

Because the program outlined here proceeds along a rather high academic plane, a heavy burden is placed upon instructors. Wherever possible, instructors should illuminate the material presented with illustrations drawn from current engineering practices and from past great achievements in engineering and science.

NATURE AND PROPERTIES OF MATERIALS

COMMITTEE:
Glenn Murphy, Chairman
R. M. King
B. J. Lazan
R. L. Sproull
T. E. Stelson
L. H. Van Vlack

INTRODUCTION

The engineering developments of the past few years have placed new and stringent requirements on materials. The demands for materials that will perform satisfactorily under difficult environmental conditions such as extreme temperatures, high stresses and irradiation have emphasized the need for a better understanding of the nature and properties of all materials. Concurrently with these demands there has developed an increasing awareness of the importance and power of basic scientific principles which serve to coordinate the body of knowledge associated with materials. A unified group of concepts and principles is now emerging as a result of the interchange of ideas among workers in fields such as chemistry, solid state physics, metallurgy and ceramics.

This evolution from the empirical to the scientific approach to materials is occurring in all branches of engineering because each involves the utilization of materials. New applications of principles have resulted in developments undreamed of, or considered impossible, only a few years ago. For example, critical studies of crystal imperfections brought about the development of transistors and other solid-state devices, and in the mechanical field, these same studies have led to a better understanding of deformation and strength properties.

In view of the foregoing developments, it is imperative that each engineering college re-examine the emphasis and viewpoints of the courses in materials to see whether or not its faculty is keeping pace with present-day needs of the engineering graduate and is laying a foundation for the understanding of materials that will be required of the graduate during his professional career.

In many current college courses the study of materials is largely descriptive and borders on a handbook treatment of little permanent value. In the opinion of this committee the emphasis and viewpoint should be such that the program in materials may rightfully be classed as an engineering science—the science of materials.

Purpose of this Report

The purpose of this report is to present the objectives of a program in the science of materials, to outline the concepts that form the core of the science of materials, to call attention to some applications and illustrations, and finally, to suggest a few of the many ways in which the program may be implemented. It should be emphasized that this report is not intended to outline a single course or series of courses in materials, nor is it intended to indicate minimum requirements. However, the concepts enumerated in the report are those considered essential in

providing a basis for the understanding of materials at the level that will be required of graduates from our engineering curricula if they are to function most effectively as professional engineers in the future.

TEACHING THE SCIENCE OF MATERIALS

Objectives

The objective of a program in the science of materials is to assist the student in developing an understanding of the behavior of materials as a logical consequence of the interaction of the structure of the material and the environment in which it is used. In this understanding, the student will have a rational and powerful tool for immediate engineering applications and, of greater importance, will have the potential for virtually unlimited future penetration of the subject. If he is to continue to develop in the field, his knowledge of materials must not be circumscribed by an art that is outdated. To facilitate immediate application as well as future developments, he must be led to a broad understanding of the behavior of materials as manifested by their properties. Thus, the subject becomes a study of the interrelationship among properties, environment, and structure.

If a fundamental understanding of the role of structure throughout the vast field of materials is to be attained, structure must be considered through the spectrum of physical arrangements ranging from sub-atomic through atomic, microscopic, macroscopic and on to phenomenological considerations. In other words, structure must be interpreted to include nuclear structure, electronic structure of atoms, aggregates of atoms, (molecules, crystals, noncrystalline solids), aggregates of solids (poly-crystalline metals and nonmetallic materials, multiphase materials), and the states of matter such as gases, liquids, solids and their aggregates (gels, fogs, smoke and emulsions). The environmental parameters which, together with structure, control the properties of engineering significance include temperature, time, irradiation, mechanical forces, electric and magnetic fields, and chemical conditions.

A number of fundamental concepts are essential in developing a basic understanding of the interrelationships among properties, structure, and environment.

Concepts

Some of the concepts considered essential in the science of materials are usually presented in basic physics and chemistry courses. At many institutions the courses in physics and chemistry already include the following preliminary topics:

1) Structure of nuclei
2) Electronic structure of atoms (orbits, size, quantum numbers exclusion principle, periodic system)
3) Elementary kinetic theory

If these topics are not treated adequately in the basic science courses, they should be incorporated into the engineering science program. If they are treated in basic science, the materials program can be built on them to develop the implications of nuclear and atomic structure as related to the properties of gases, liquids and solids.

The heart of the engineering science of materials includes the following concepts:

1. Interatomic Forces
   a. Types of forces
   b. Relation of type of force to valency

c. Arrangement of atoms in molecules

2. Crystal Structure
   a. Crystal symmetry
   b. Interplay among coordination number, atomic size, and crystal structure (hard-ball model)
   c. Solid solutions
   d. Order-disorder
   e. Isotropy and anisotropy

3. Energy Bands in Solids
   a. Relationship between energy levels in atoms and energy bands in solids
   b. Electron motions
   c. Filled and partially filled energy bands

4. Imperfections in Crystals
   a. Types of imperfections
      (1) Thermal vibrations
      (2) Waves of excitation energy
      (3) Interstitial atoms and vacancies
      (4) Free electrons and holes
      (5) Foreign atoms
      (6) Dislocations
   b. Governing of behavior by imperfections
      (1) Electrical conductivity
      (2) Mechanical strength and deformation
      (3) Transistor action

5. Atomic Motions in Materials
   a. Mobility (and trapping) of imperfections
   b. Diffusion

6. Phase Equilibria and Phase Transformations
   a. Equilibrium diagrams
   b. Nonequilibrium structures
   c. Microstructure
   d. Nucleation and crystal growth
   e. Recrystallization
   f. Colloidal systems

7. Boundaries
   a. Surfaces
   b. Grain boundaries
   c. Electrical effects at surfaces
   d. Absorption and catalysis
   e. Electron emission

8. Noncrystalline Materials (Plastics and other Polymers)
   a. Polyelectrolytes
   b. Chelating agents

9. Fields and Concentration Gradients as Driving Forces
   a. Transport of electrons and holes
   b. Alignment of electric and magnetic dipole moments
   c. Diffusion

The foregoing concepts are essentially the same as those recommended for inclusion in engineering curricula at the Allerton Park and Carnegie Institute of Technology Conferences on Solid-State Physics sponsored by ASEE and the National Science Foundation.

Illustrations and Applications

Specific illustrations and applications of the concepts are essential in developing a real understanding of how properties are controlled by structure and environment. The following examples represent some possible situations where the presently known interaction of structure and environment affects or helps explain the behavior of materials. The

list is not intended to be complete or exhaustive but is given to indicate something of the breadth and scope of the subject matter.

GENERAL AREAS OF MATERIAL UTILIZATION	EXAMPLES OF CHARACTERISTICS
Electrical	Conductivity, semi-conductors, p-n junctions, superconductivity Dielectric properties
Thermal	Conductivity Heat capacity Expansion
Mechanical	Stiffness Strength and deformation Viscosity and viscoelasticity Magnetic-mechanical damping Surface tension
Magnetic	Ferro- and ferri-magnetism Permeability
Chemical	Corrosion Electro-chemical cells Solubility
Optical	Color and transparency Reflectivity and emissivity Luminescence
Irradiation	Damage Absorption

In addition, many of the most interesting and valuable properties include more than one general area of behavior. For example, piezoelectric effects include electrical and mechanical properties, photoconductivity includes optical and electrical properties, and radiation embrittlement includes irradiation and mechanical properties.

Presentation of Material

It is well recognized that there are three basic ways in which new material may be introduced into a student's program. New courses may be introduced, either to replace other courses or to increase the curriculum content, existing courses in the field may be reorganized and brought up to date by discarding obsolete or less essential topics, or references may be made to the new material in related applied or design courses. That is, to activate a new program in materials, the old courses may be dropped and entirely new courses added; existing courses may be modified by deleting topics such as details of blast furnaces, foundry practice, and operation of pug mills, and substituting topics such as imperfections and their effects; or the fundamental concepts may be introduced in subsequent engineering technology courses such as design.

It is also recognized that a course or a program in the science of materials may be taught from many different

approaches. The principles may be introduced, deductions made, and examples cited; or the principles may be developed from a few special cases and later applied to other cases. A given course may thus start from a consideration of structure, of environment, or of properties.

The engineering science of materials as outlined previously does not necessarily cover all of the aspects of materials essential for engineering design in all branches of engineering. For example, an effective course in machine design requires some understanding of metal working and forming. The committee thus recognizes that such practical consideration of materials is necessary in varying degrees in the engineering analysis and design areas of individual curricula. However, the analysis and design studies of materials applications and materials processing should be firmly based on the engineering science of materials and should not be considered as substitutes for the science.

This committee is not recommending any particular sequence of topics, any specific course arrangement or any fixed program for the teaching of the science of materials, but it does recommend a new and more fundamental treatment of the science. It recommends that the science of materials be taught, not as a collection of unrelated facts but as a science based on chemistry, mathematics, and physics, at a level consistent with the maturity of the student. The committee recognizes that a suitable program at one school may be entirely unsuitable at another, that experimentation is desirable, and that there is no single "best" design of a course—each usable design being a result of compromises. The committee believes that the creativeness of the engineering faculties in developing their own programs and integrating them with the policies and objectives of their respective colleges can be depended upon to improve greatly the offerings in the science of materials.

The committee recommends the inclusion of demonstrations or laboratory work in the program of the science of materials. The following list is indicative of the types of experiments that have been used successfully in illustrating various concepts and principles in the subject.

1. Motion picture on bubble model of dislocations (British)
2. Motion picture on magnetic domains (Bell Labs)
3. Motion picture of dislocation movements (Univ. of Calif.)
4. Tensile tests of single crystals and polycrystalline aggregates
5. Construction of models of molecules and crystals
6. p-n junction characteristics
7. Diffusion
8. Age hardening or hardening of steel
9. Internal friction of metals as a function of temperature
10. Photochemical effects in alkali halides
11. Photoconductivity of vidicon tube
12. Microstructure of metals and alloys
13. Creep

In a program dealing with the newly emerging science of materials, good teaching is paramount—its importance cannot be overemphasized. In this particular field rather unusual teachers are necessary as they must be well grounded in the basic sciences and also know the practical applications which will stimulate the students and give depth and breadth to their understanding of the subject.

ENGINEERING ANALYSIS AND DESIGN

COMMITTEE:

D. W. Ver Planck, Chairman
J. E. Arnold
E. E. Day
R. E. Fadum
M. S. Gjesdahl
D. L. Katz
D. H. Pletta
E. R. Schatz
Dana Young

INTRODUCTION

The *Report on Evaluation of Engineering Education – 1952-1955* emphasizes the importance of engineering analysis and design by stating that "approximately one fourth of the total undergraduate program may be appropriately devoted to engineering analysis and design, including the necessary technological background." The report goes on to say "The capacity to design includes more than mere technical competence. It involves a willingness to attack a situation never seen or studied before and for which data are often incomplete; it also includes an acceptance of full responsibility for solving the problem on a professional basis." Further, in this connection, the report says that mathematics, the basic sciences, and the engineering sciences "shall be used proficiently in engineering analysis, in the study of engineering systems, and in the preparation for creative design work." The strong emphasis on the importance of design in engineering curricula is of course not new. In the past, however, design courses generally have dealt principally with current design practices and the art of engineering. But with the ever accelerating pace at which wholly new scientific discoveries are coming into the province of engineering the need is for engineers who can use new science, or old science in new ways, to design creatively at a high level. Thus by fairly common consent the emphasis on current practices must be minimized or eliminated in the curricula of the future to make room for a more fundamental education.

The task of this committee is to study the methods and philosophy of developing the creative ability in students through work in engineering analysis and design. The purpose of the study is to define the unique characteristics of engineering analysis and of engineering design and to discuss the philosophy and techniques of teaching, giving particular attention to their interrelations and methods common to various professional areas, as well as the necessary technological background.

It is important to note at the outset that we are not trying to propose courses of specific factual content, but are proposing a very definite engineering philosophy and methodology that should underlie and be a part of all of the students' intellectual experience at the college. We recognize that the divisions of time listed in the Evaluation Report may not be easy to identify and total by course name, for it is hoped that the essential features of engineering activity and the fundamental mode of thinking outlined in this report will guide the teaching of the basic and engineering sciences as well

as those courses that might be called engineering analysis and design.

We believe that the ideal engineer should be characterized by three attributes:

1. His ability to handle creatively the problems relating to the basic physical needs of man,
2. His ability to integrate the many facets of engineering science that may be involved in these complex and comprehensive problems,

and at the same time

3. His ability to reflect his expertness in specific fields that he has explored in depth.

The report is devoted first to a discussion of what is meant by engineering analysis and design and the underlying modes of thinking, and then turns to a discussion and examples of teaching methods for developing creative ability.

THE MEANING OF ENGINEERING ANALYSIS AND DESIGN

To describe concisely what is meant by engineering analysis and design is as difficult as to construct a brief and yet meaningful definition of engineering itself. To convey the same connotation of these terms to everyone who may be concerned seems to require consideration from a number of different viewpoints.

In the simplest, most direct terms, engineering analysis and design, as used here, mean evaluating an existing system or devising a new one in situations arising anywhere in the complex and continuous spectrum of engineering activity. As examples, consider the following typical engineering situations.

1. Original perception of the need for a design. This might evolve from a systematic study of an existing situation, or at another extreme, it might be the result of a flight into pure fancy.
2. Creation or synthesis of a design to satisfy the need perceived. This is likely to be a recombination or new use of old ideas and, in some cases, may result in original invention of the patentable sort.
3. Evaluation of a design in comparison with other designs and in terms of the original need.
4. Analysis of an existing engineering system or device with a view to determining its characteristics and improving its performance or economy.

The first two of these functions relate to "design" and the latter two to "engineering analysis." These functions rarely occur separately, but merge into one another. The listing is in descending order of the creativity needed, but in terms of mathematics required, the order in most cases would be reversed. However, engineering analysis as used here is not synonymous with mathematics, although mathematics, of course, is an essential tool. Engineering analysis includes the principles and techniques, including experimental ones, of all pertinent sciences. Design does not necessarily mean something associated with drafting, although it is true that graphical methods may be useful in the process of creating and communicating ideas and designs.

Functions such as listed above are all characterized particularly by *original thinking, exercise of judgment* and *decision making*. The engineer faces a situation or perceives a need which has not arisen before, at least to his knowledge, and then by well-ordered thinking he arrives at solutions or designs that satisfy the situation or need. Finally, on the basis of his judgment and the work he has done he makes a decision and recommends action. There are degrees of newness in the situations or needs and hence

degrees in the level of originality required, but engineering analysis and design means something above the level of mere performance of steps in an established routine without the exercise of critical judgment.

Although engineering analysis and design are different functionally, both are characterized by similar mental processes and approaches. For example, the analysis of engineering problems and the creation of engineering designs involve one or more of the following:

1. *Search for alternatives.* In the creative process the alternatives are all the likely ideas that one can conceive; in analysis they are the physical principles and mathematical methods that one might employ.
2. *Simplification.* This is the elimination of everything but the essentials of the design to be created or situation to be analyzed. It may be the creation of a model or system which facilitates the study.
3. *Breadth and flexibility of view.* This encompasses a study of the situation as a whole, not merely of some narrow aspect which may happen to coincide with one's own specialty. Typically, it is being open-minded, that is, considering the situations without prejudices or preconceived notions.
4. *Facility in the use of fundamental principles.* This is the ability to apply the relevant bodies of organized knowledge such as the basic and engineering sciences, mathematics, and the life and social sciences to aid one in solving the problem, be it a design or an analysis.
5. *Decision making.* The ability and willingness to make decisions is basic in every step of design or analysis.
6. *An alert curiosity and readiness to learn from experience.* This is being receptive to all ideas so that they may be available for use in situations calling either for creativity or for analytical power.

At the risk of oversimplifying, it may be useful to think of a problem in engineering design in a mathematical framework. If one were able to formulate a design problem in mathematical terms he would find the formulation characterized by the following:

1. Fewer equations to be satisfied than there are unknowns, or variables, to be determined.
2. Inequalities to be satisfied, for example, "not over 30,000 psi stress," "not less than 100 hours of life," and so forth.
3. A "pay-off" function to be minimized or maximized, which not only pertains to the design itself but includes consideration of the time and cost of arriving at the design.

Thus, in distinction to a purely analytical problem, a problem in design leaves wide latitude for the play of creative imagination and the exercise of judgment in the search for solutions.

Basic Modes of Thinking

A difficulty in discussing engineering analysis and design arises because engineering analysis includes more than is implied by the word, analysis. Likewise, design is not limited merely to synthesis. *Analysis* and *synthesis* and also *evaluation* are basic modes of thinking which are probably independent, or at least partly independent, of each other. Engineering analysis and design each require these three basic kinds of thinking, analysis, synthesis, and evaluation, but perhaps in different ratios.

Top level creative design, the activity that leads to major innovations in science

and engineering, depends on maintaining a proper balance among the modes of thinking.

The modes of thinking—analysis, synthesis, and evaluation, probably develop in a very definite sequence, and the effective mental activity associated with any of these modes depends, in part, on the mastery of the modes that preceded it in the development process. The first mode to develop is analysis. When the infant first becomes conscious of himself and the world around him, when he becomes aware of the different sensations impinging on him, when he attempts to categorize these sensations and, in effect, to change sensation into perception, he is using analysis as his only thinking tool. He is "analyzing" one "thing" at a time. Before long, however, the child can handle two and more "things" at a time, and this is basic to the process of evaluation. It is impossible to evaluate a single object or idea at a time. Occasionally it may seem as if we are, but actually we are considering two objects, one real and tangible and the other fabricated out of the sum total of our past experience. It is probably obvious that the most effective evaluation (comparing, value judging, rating, classifying, deciding, and so forth) is dependent on keen analysis of the various objects involved.

The last thinking mode to develop and probably the first to be destroyed as an unfortunate consequence of the usual educational process is that of synthesizing, the bringing together of two objects or concepts for the purpose of making a new combination or whole. When this is done in the mind we call it imagination. *High-level,* effective synthesizing might be synonymous with creative design if we recognize that it must also include keen analysis and thoughtful evaluation.

We say that the synthesizing ability is the last to develop and the first to be inhibited or destroyed. Closely following in the destructive process is the ability to make judgments and decisions. This is probably the result of devoting practically all of our formal education time (and a good share of informal education time as well) to exploring, explaining, and exercising the process of analysis as a mode of thinking, arriving at the *one* right answer to the problem or task confronting us. We learn the *one* right way to spell cat, the *one* right answer to two plus two, the *one* right answer to "Who won the Battle of Hastings?" and the *one* right deflection at the center of a beam, uniformly loaded and freely supported at the ends.

Now the learning of these things is not wrong, but the learning of *only* these things is undesirable if we want to have competent creative engineers as well as competent creative citizens. Analysis is necessary, but not sufficient. The evaluative and synthesizing abilities must also be explored, explained and exercised; and this must start in the first grade and continue through the doctorate. When this is done properly every instructional unit (whether it be a course or a term) will contain aspects of all three modes of thinking, although not necessarily in equal ratios. The understanding must grow; the exercise must be continuous.

EDUCATION FOR ENGINEERING ANALYSIS AND DESIGN

It is essential that all courses and curricula be reexamined to see how evaluation and synthesis can be exercised in courses now primarily analytic. All courses do not have to maintain the same balance, but no course should use analysis alone. The inclusion of evaluation and synthesis in all courses will not be an easy task, and may take many years to accomplish fully. Until a proper balance can be obtained in the entire educational program, an immediate effort

should be made to include evaluation and synthesis in the existing courses which are most easily adapted to this. These might well include laboratory and drafting courses.

It is further recommended that special courses emphasizing the use of imagination and more fully exercising the creative talents be experimented with and included in the curriculum at various levels. Indeed a good deal along these lines is already being accomplished both at the institutional level and by many individual teachers.

An essential value to be derived from education in engineering analysis and design is integration of the engineering, basic sciences, and mathematics already studied. By applying a principle or method on his own initiative in situations which are new to him the student develops the deep, firm understanding and self-confidence that are characteristic of the professional man. Problems, or other educational experiences in this phase of the curriculum, should require the student to work at the highest level which he has attained at the time of the assignment. Moreover, education in engineering analysis and design should be continued to the very end of the curriculum so that the student has opportunity to apply by himself all that is included in the curriculum and at the highest level. Conversely, there is little reason to include material in the curriculum that the student is not likely to integrate in this way.

In the latter part of the curriculum the student's professional specialization may include both work in engineering analysis and design and study in one or more appropriate engineering sciences beyond the "hard core." Such work in engineering analysis and design may include special techniques of analysis or of synthesis appropriate to the professional field.

The student should be taught to deal with *whole* problems, not merely ones limited narrowly to his field of specialization. Not only should he learn to take into account all of the pertinent physical and economic factors, but he should learn to complete his job by presenting his design or his recommendation in an appropriate and effective manner.

The remainder of this report is devoted to examples of courses and problems which it is believed will be helpful to those seeking ideas on how to develop the parts of curricula devoted to engineering analysis and design. The examples are taken from the teaching experiences of the individual committee members. They do not represent all of the engineering fields and are intended merely to be suggestive of what may be done.

It is most important to consider the examples in relation to the experience and educational level of the students concerned. One must never forget that what is trivial for a senior may be a major challenge for a freshman. Viewed in another way, the solution to a particular problem by a freshman may be vastly different from that by a senior, but both may be equally good when due consideration is given to the respective levels of experience.

Exercises in Creativity

It is possible to develop and encourage creativity in the student by challenging him from time to time with situations requiring true creativity, and one way of doing this is by simple problems which have no analytical or unique answer. Problems of this nature, similar to the examples given below, should be chosen so as to require creative thinking, but should be simple, and be specific. They may be given at any time in the students' academic career and in a variety of courses such as machine design, mechanics, engineering analysis, mechanisms, dynamics or other courses

where need for creativity and freedom from stereotyped problems is felt. Such creative problems are successfully solved by the kind of thinking which has been emphasized in this report.

These examples have been found useful with beginning sophomores and graduating seniors. They have been used as home assignments and as 15-minute class papers. The essential point of them is that they focus directly on creativity unclouded by need for analytical or other special skill.

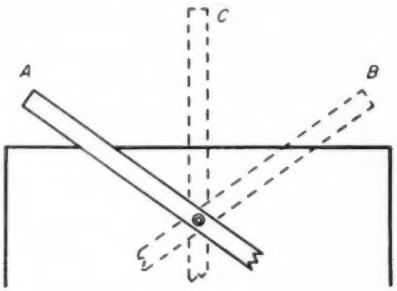


FIG. 1

PROBLEM 1. The handle shown in Fig. 1 is to have two functional positions which are at A and B. It is necessary, however, for the handle to be stopped at position C before proceeding to position B and the same on the return. Devise a simple, foolproof scheme within the box which will assure this pause in position C.

PROBLEM 2. A ¾" round bar is moved longitudinally against the force of a long tension spring that is parallel to the bar and attached to the bar somewhere along its length. The axes of the bar and spring are offset. Sketch a simple effective connection of the spring to the bar that will be *firm*, yet freely *adjustable*.

PROBLEM 3. Vertical shaft A in Fig. 2, turning as shown, is to drive the rollers on axes B and C in the directions indicated. Axes A, B, and C lie in the same vertical plane, B and C making angles of 30 degrees with the horizontal. Sketch a design which you believe would would be a satisfactory solution of this problem.

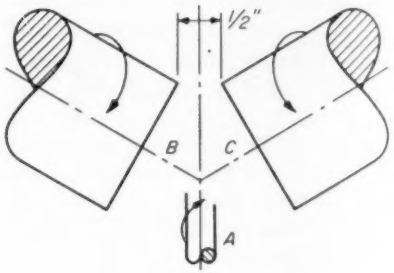


FIG. 2

PROBLEM 4. This problem, Fig. 3, actually developed in the design of a lubricating mechanism and is as follows: A mechanism or part of a machine is to be designed which will automatically give on-way rotation (not intermittent) to a driven shaft while the driving shaft rotates in either direction. The driven shaft does not rotate, of course, while the driver is still during its reversal. No special amount of torque is specified. Sketch as compact and as simple a design as you can, which you believe will do the job.

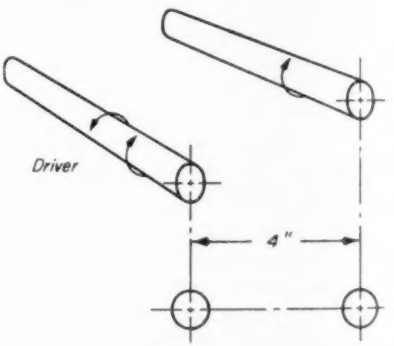


FIG. 3

PROBLEM 5. Levers A and B of Fig. 4 operate shifting gears through links attached to eccentric pins C and D. The gears are shifted to their operating positions by moving the handles from

their horizontal positions (shown in full lines) to the vertical positions (shown dotted). Sketch a simple design which will prevent both handles from being in their operating positions at the same time. The gears begin to engage when the handles are 15 degrees above the horizontal position. In other words, one handle must be below 15 degrees when the other is above 15 degrees.

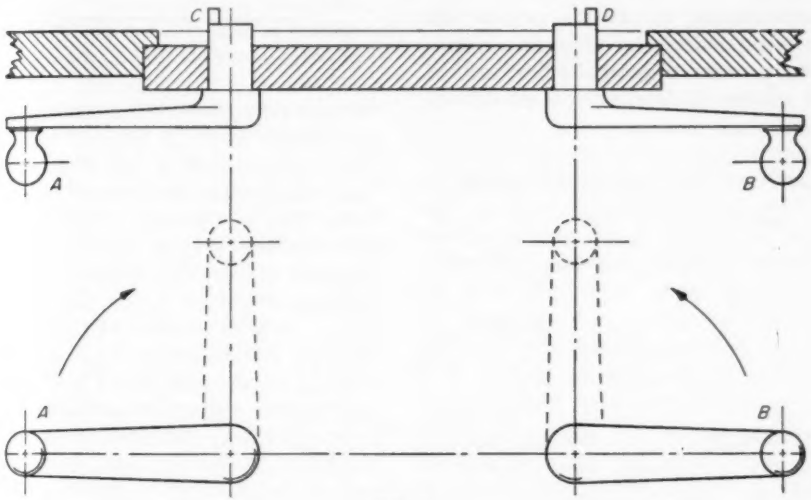


FIG. 4

Design Problems in the Laboratory

Often a routine laboratory exercise can be made into a problem requiring original thought by the student simply by changing the way in which the assignment is made. For example, a routine laboratory assignment to juniors in chemical engineering may be given as in problem 6.

PROBLEM 6. Determine the heat transfer coefficients of the forced circulation evaporator when evaporating a 20 percent solution of organic chemical at 212°F, using a 5 percent solution at 150°F as feed. Use a steam pressure of 10 psi.

A problem requiring ultimately the same laboratory operations but a very different pattern of thinking by the students might be made in the form of an interoffice memo, as given in problem 7.

PROBLEM 7. The following interoffice memorandum has been referred to you for reply.

From: *Chief Engineer*
To: *Junior Engineering Group*
Subject: *Forced-Circulation Evaporator*

We have been requested to furnish the necessary information for design of a minimum-cost forced-circulation evaporator to concentrate a 5 percent aqueous solution of a high-molecular-weight organic chemical to 20 percent. 16,000 pounds of weak solution is fed each hour at 150°F. The maximum boiling temperature is 212° F, and steam is available at 10 psi. Will you please supply the information needed for this design, along with your recommendations.

A combination homework-laboratory assignment given early in the first sophomore course in electrical engineering is problem 8. The students know Kirchhoff's current law and have been given

information about switches and simple relay circuits. They have no information on the design of switching circuits. Whatever principles or methods they use to solve the problems must come out of their own minds and their own experiences. In the second part of the problem students are given an opportunity to extend or generalize their method of solution to a slightly more difficult case.

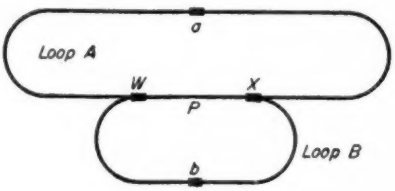


FIG. 5

PROBLEM 8. (a) A model railroad has the track layout shown in Fig. 5. The two sections labeled a and b are single-contact normally-open switches that close when a train passes over them. They can be used to operate relays. W and X are track switches that are solenoid-controlled and, in the released position, are set to send the train to loop A. Devise a switching circuit that will send the train in sequence around loop A, then B, and then A again, starting from point P.

(b) A new section of track has been added to the railroad described above, as shown in Fig. 6. The track switches are all set to send the train straight through in a released position. a, b, and c are single-make contacts which close as the train passes over them. It is desired to have the train start at point p and go around loop A, then C, then B, then C, and then start over again. Design the relay system to do this.

The elements of synthesis and analysis are clearly present in problem 8. Evaluation—in this case, the comparison of the many designs possible—comes in

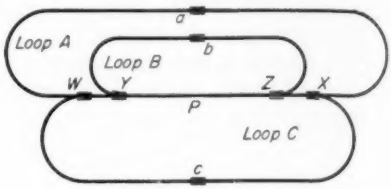


FIG. 6

the laboratory when various groups set up their solutions to the problem. It soon becomes obvious that some solutions have fewer relays than others, and that, from an economical design view, these solutions are better than the others. For many students this now poses a new problem, namely, to design the circuits with a minimum number of relays and switches. The notion of an "optimum design" has been introduced in an easy and natural way. This problem, together with the descriptive material on relays and switches, takes about one week of homework time and one week of laboratory time.

Laboratory problem 9 is assigned at about the time resonance phenomena are studied in a course on a-c circuits. It is a good example of the way a somewhat standard laboratory exercise —in this instance, the observation of series resonance—can be reworded to introduce elements of creativity. All procedures of the usual exercise are retained in this new version, but the emphasis for the student has been changed from passive observation to active interest because there is a job to be done and a circuit to be invented.

PROBLEM 9. It is of great importance in a-c systems to determine the frequency accurately. Commercial frequency meters ranging in construction from vibrating reeds to electronic null counting devices are on the market. An example of a very simple frequency measuring method is the use of a voltmeter, ammeter, and a standard capacitor. Then

$$f = \frac{I}{2 \pi CV}$$

But this method, for obvious reasons, is not precise enough to distinguish small changes in frequency. Combinations of inductances and capacitances lead to circuits in which currents and/or voltages change more rapidly with frequency, especially in the vicinity of frequency resonances. But, since equal values of voltages and currents occur on either side of resonance this method may be ambiguous. To eliminate such trouble one possibility is the use of the phase sensitive characteristics of a wattmeter in a resonant series RLC circuit in order to yield a direct reading frequency meter. The laboratory work of this week relates to such a circuit. The laboratory problem for this week is the design and assembly of such a frequency metering circuit. It is to be constructed with the available circuit elements and meters. Assemble a system which yields a meter scale that could be calibrated so that it is direct-reading and single-valued over the range of frequencies from 55 to 65 cps. It should respond to very small changes in frequency.

In problem 9 the student is given possible parameters to be included in the design. He must use these to construct a frequency meter, or, if they do not seem adequate, use others. Whatever circuits he invents must be analyzed to determine whether or not frequency can be measured and then evaluated and compared to ascertain which of them respond to very small changes in frequency. This problem is assigned for about one week or ten days in advance for solution during one laboratory period.

It might be pointed out that the laboratory assignment described as problem 9 is part of a course whose main purpose is the teaching of circuit theory and that no unusual laboratory facilities are required for it. The main purposes of the course are in no way hindered or delayed by this assignment, but, rather, can be enhanced by it.

A project of several weeks' duration, incorporating both analytical and experimental aspects is problem 10. It has been used in a course in rotating machines at either the junior or senior level. The student is asked to invent an integrator using a d-c machine and then evaluate it in comparison with the more usual circuits. In carrying out this assignment the student must first consider the several possible ways in which the d-c machine can be used as an integrator (there must be three or four) and then check their practicability in the laboratory. The evaluation process will most likely necessitate considerable study on the student's part of the existing methods of integration.

The completion of this project requires as deep and thorough a study of the d-c machine as is now included in the more standard machinery laboratories and, in addition, poses a problem which requires from the student a final conclusion and recommendations. In other words, in this acquisition of technological knowledge concerning d-c machines, the student is functioning as an engineer and is learning to learn by himself.

PROBLEM 10. Integrating devices are used in many engineering applications. One of these applications—the electrical analog computer[1]—has received much publicity in recent years. The purpose of this laboratory problem is to investigate the possibility of using the d-c machine as an integrator and to compare its performance of this function with those of more widely used methods. Finally, you are asked to consider whether or not there may be areas of operation in which the d-c machine, used as an integrator,

[1]See, for instance, the article in the November 1956 issue of *Electrical Engineering*, page 1045.

is actually superior to presently used devices.

Some Design Problems in Civil Engineering

An assignment involving considerations of the effect of landing gear configurations and tire pressures on pavement design and required lengths of runways in consideration of means that might be employed to accelerate and decelerate aircraft is presented as problem 11. Full consideration of the problem may lead the student to the conclusion that it is not practical to land or launch an aircraft of such size from a conventional runway. It will challenge his creative ability to suggest alternatives.

PROBLEM 11. The airplane of tomorrow will weigh 1,000 tons and will have a landing speed of 300 miles per hour. In consideration of launching and landing problems relating to such an aircraft, which restrictions would you impose on the aircraft designer?

Problems such as number 12 are given to students in municipal engineering or advanced undergraduate students who have completed their transportation engineering courses. The students have had instruction in the fundamentals of urban and regional planning. The problem attacks the land-usage characteristics of a community in terms of the transportation system. It requires the student to analyze the transportation problems caused by different land-use arrangements. The student must make several fundamental types of design, considering the type, magnitude and need for a central business area. The concept of complete decentralization of activities must be compared with centralized locations for industries and business. In general, the student must prepare at least two basic types of design (centralized versus decentralized), which he must then reanalyze in terms of the transportation problems that are created. Finally, some economic study must be made of the utility system and other municipal services that must be provided.

PROBLEM 12. It is axiomatic that the street system of our American cities was not developed for automotive transportation. Generally our existing street system was thought of historically as merely an access to property. Automotive transportation has changed our living habits. It appears that in future years we shall own approximately two automobiles per family. The average family will need approximately half an acre for living purposes. One family will generate four to five automotive trips per day. As students in transportation engineering, you have made a study of land usage, of desirable relationships between living, working and shopping, and you are familiar with the concept of sound land-use planning. Assume that you are to design an urban area for an initial population of 200,000 that is expected to develop ultimately to a population of 500,000. This urban area will be balanced in terms of industry, business and residences such that the community is reasonably self-sufficient. The urban area is to be situated approximately 20 miles from several other smaller satellite urban areas. The proposed urban area is to be designed for private automotive transportation with railroad facilities for the delivery of bulk materials. Mass transportation will not be provided.

(a) Prepare an idealized plan for the the proposed urban area, showing various land-use subdivisions and the street system that would be required to serve them.

(b) Prepare estimates of probable traffic volumes. Designate the number of traffic lanes that will be required and the type of facility (freeway, arterial route,

etc.). Dimension the living, shopping and working areas.

(c) Prepare a written report pointing out why the concept that you propose is more desirable or more efficient than the types of urban areas that exist today.

A problem for the undergraduate student in transportation engineering is number 13. The elements are kept to a minimum. Basically, the student must evaluate various designs with respect to the number of vehicles that can be accommodated with due consideration to circulation problems. Circulation through the lot is affected by the type and location of spaces. Entrances and exits must be designed, with due allowance for "stacking up" of vehicles, so that the vehicles in the lot will not be prevented from circulating.

PROBLEM 13. Given an area with dimensions 200 x 300 feet at the intersection of two important business streets. Prepare a design for the use of this area as an off-street parking lot for shopper parking. The lot will be self-service and operated by parking meters. The average length of parking will be two hours. Parking stalls are to be 9'-6" by 19' for angle parking and 8' by 22' for parallel parking. The average turning radius of the vehicles can be assumed to be 23'. Entrances or exits may not be within 100' of the street intersection and two curb cuts only are permitted on each street. The curb cut is restricted to 30'.

PROBLEM 14. A power plant, a paper company, and a small community are located on a stream which discharges to the ocean.

(a) The power plant requires cold, oxygen-free water that can best be obtained from near the bottom of a deep lake. The conditions at the bottom of such a lake, however, promote the solution of iron and manganese from biological materials.

(b) The paper plant requires large quantities of water free of iron and manganese, but discharges a water that has a high demand for oxygen.

(c) The community requires water that is very pure for domestic uses. The town depends for its existence on employment by the power company and the paper company, recreational and commercial fishing, and farming that requires irrigation.

(d) The stream is the spawning ground for a type of fish that provides a livelihood for a large area along the ocean.

Devise a scheme for locating the plants and allocating the water resources equitably among these several interests.

A Creative Course in Machine Design

Before an engineering student completes his undergraduate career he should have an opportunity for professional experience in meeting situations similar to those which occur in practical engineering. A design course should be available which places on the student the responsibility to complete assignments within specified times, and which requires that he develop solutions to problems with his accumulated knowledge and creative talent.

The problems selected for assignment should attempt to integrate the broad area of the engineering curriculum. In mechanical engineering, for example, design problems may involve fluid flow, heat transfer, control systems, lubrication, and heat power, in addition to the general requirements of drawings for manufacture, assembly, operation, installation, maintenance, and economy.

To avoid specialization in any one type of design problem, one or several short "warm-up" design problems may be as-

signed to emphasize the desired mental approach to design situations. Manufacturing drawings may be needed for a simple problem, such as the design of a ball or roller bearing trunnion for a large rotating lime kiln. One specification may require that the axial tolerance in assembly be kept within the limits of .010 to .030 inches. The students may be allowed twenty to twenty-four hours to produce detail drawings and an assembly to satisfy the specifications given by the instructor. The appearance of the design is left to the student, who is encouraged to select materials, proportion the parts and make decisions in regard to machining and assembly.

The function of the instructor in this course is to lead, to encourage, occasionally to suggest, to supply professional experiences, and to help overcome frustrations and stimulate imaginative effort in students.

It may be assumed that the students have completed required fundamental courses and that a fifteen-week semester in the first part of the fourth or senior year is available, with class hours arranged as two three-hour periods or as three two-hour periods per week in the design room. A one-hour lecture period per week is desirable to present material to all sections at one time.

The lecture period offers an opportunity for the instructor to assign short analysis problems or brief report projects which require written statements of the conclusions, such as would be required of an engineer by a plant manager. The number of these problems, which are in addition to the drawing room design projects, may vary and each may require one or two weeks for completion.

The main assignment of the course, allowing eight to ten weeks, may be one project for all students or several, from which each student may select one. The function of this project is to simulate conditions in industry. All the data are known, and general information is available. In fact, manufacturing companies may be approached for suggestions of problems which are appropriate for use with students.

An example of one project which has been given to students who have completed three years of academic work in mechanical engineering is the design of a portable power nail hammer to drive 4-, 6-, or 8-penny nails into wood. The general specifications state that a ¾-hp electric motor, running at 20,000 rpm at no load and 10,000 to 12,000 rpm at full load, is to be used. The motor rotor, if available, may be weighed or the weight determined from the proportions of the rotor. Details of the motor and characteristic operating data may be provided. The motor is used to operate a mechanical impact device through a suitable reduction unit. The complete design of the nailing tool shall not exceed 18 to 20 pounds to permit easy handling. A clip to hold nails may be assumed to be available, or be incorporated in the design project, and provision for feeding nails is required. Safety features are necessary so that nails cannot be shot through the air.

Energy requirements for driving nails into pine, fir and birch wood may be obtained from the U. S. Forest Products Laboratory in Madison, Wisconsin, and from the Virginia Polytechnic Institute, where research work has been conducted.

The development of the project may be discussed in the one-hour lecture period. The general requirements for the mechanical drive, components, manufacture, methods of assembly and materials should be covered.

During the time allowed for this project, the students are encouraged to develop *their* ideas, to be imaginative, to analyze *their* proposed designs. The instructor should encourage suggestions and may have a 15-minute session with the class to obtain ideas which may be

used in a solution to a particular phase of the project. Such a session should tend to overcome inherent frustrations which some students may have.

At the end of the time allowed for the project, a layout assembly drawing is required, and this assembly shall be discussed by the student before a panel of 3 engineering staff members, one of whom shall be the student's instructor. After his brief presentation, of five to ten minutes, explaining the features of his design (how it works, how it is assembled, how it is cooled and lubricated) and any other factors of which each student is previously advised are to be covered, the panel members ask questions which are critical and may indicate that the design does not meet the given specifications. About fifteen minutes are allowed for each student in class periods during the last week of the semester. Each member of the panel evaluates the student's design on the basis of originality and unusual features and on the manufacture and assembly. (It is of interest to note that some students exhibit characteristics of being able to "sell" their ideas to the panel.)

The projects used in a course of this type must vary each year to encourage creative thinking and application of course material previously covered. A static course content defeats the objective. The projects require active participation by the instructor in stimulating student thinking toward analysis, synthesis, evaluation and design development. The instructor removes as many barriers as possible to permit freedom to the student to explore ideas relative to the assignment. Instructors will find that students usually resist having this freedom because methods of instruction in previous fundamental courses were to assign practice problems which left only one unknown for the student to determine.

To overcome the general tendency to lean on the instructor, students should be asked "what is your idea?" "suppose you suggest a method." When the question, "how do you want me to do this?" is asked, it is suggested that the instructor emphasize the use of an idea the student has thought of. This course may do much to overcome the inhibitions developed during the preceding academic years.

Industry imposes an attitude on the graduate that he has received the training in fundamental course material and now is capable of applying his knowledge to problems which are incompletely defined and which have more than one solution. Therefore a course such as an applied design course is as close to an industrial experience as a student can get while he can still receive some guidance and assistance in the mental approach to a given project.

Certain concepts which underlie an applied design course may be obtained from the paper entitled "Teaching Machine Design for Modern Industry" by L. G. Gitzendanner of the General Electric Company, which was presented at the ASME Semi-Annual Meeting. (Paper No. 56-SA-67.)

Courses in Engineering Analysis

At one institution courses called "Engineering Analysis" are given to students in electrical engineering, mechanical engineering, and industrial management. Typically, each of these curricula has two one-semester courses in Engineering Analysis; in one case they are both at the junior level and in another, one is at the sophomore and the second at the senior level. There is also a two-semester Engineering Analysis sequence for first-year graduate students.

These courses are built around the solution of problems by the student on his own initiative. The problems relate to situations which are intended to be completely new to the student and often require him to bring together

disciplines he has studied earlier in two or more different course areas.

For example, a suitable problem may concern an electromechanical device such as a servo system. The device is described in general terms with sketches and a connection diagram, but without giving any numerical magnitudes. The student is asked to investigate whether the device can be made to perform its function accurately and rapidly. This particular problem would not be given to students who had already studied servo system analysis, but rather to ones who had had basic mechanics, elementary circuits, and the rudiments of ordinary differential equations. The problem necessitates the derivation and solution of a differential equation. The student is not told that this is required nor given hints on how to proceed. He not only finds out for himself that a differential equation is needed, but he chooses for himself an appropriate principle on which to base it.

In this case, for example, he might be able to start either from an energy balance or from applications of electric circuit laws and Newton's laws of motion. Since numerical values are not given, the student is forced to work in literal terms. Moreover, he must decide for himself what simplifying assumptions are in order; for example, whether to treat the device as a second order system and so arrive surely at usable results, or to take account of more factors at the risk of involvement in analytical difficulties. Finally, the problem is not answerable by some single number. The student rather finds the behavior of some variable as a function of time, following some input disturbance which he decides on, and then, by study of this result, seeks some conclusion about conditions to be satisfied if the device is to work accurately and quickly.

The student learns from a graduated series of experiences like this how to plan and carry out investigations of unfamiliar problems. Moreover, there is in the process an element of synthesis which requires him to bring together ideas that, in his mind, may have been hitherto unrelated—in the example cited: circuits, mechanics, and differential equations.

Some of the problems are assigned in purposeful confusion, either with a great excess of data or perhaps no data at all, so that the student must struggle to find out what the problem really is. Thus he learns by experience how to define and simplify problems so as to bring them within the range of his abilities. The best source for problems to be used in these courses is the instructor's own professional experience. However, good collections of ready-made problems for these purposes at various levels are contained in the following publications:

E. B. Roberts, *Engineering Problems*, (Westinghouse Technical Night School Press, East Pittsburgh, Pa., 1930).

Walter C. Johnson, *Mathematical* and *Physical Principles of Engineering Analysis*, (McGraw-Hill, New York, 1944).

D. W. Ver Planck and B. R. Teare, Jr., *Engineering Analysis*, John Wiley, New York, 1954).

"Illustrative Problems in Engineering," available from Engineering Recruiting Section, General Electric Company, One River Road, Schenectady, N. Y.

In these courses great emphasis is placed on checking the analysis as it proceeds, as well as the final result, and also on generalizing from what is learned in the solution. These steps require the mode of thinking we have called evaluation. The student must test his own work in the light of his experience or in comparison to related things he knows are true. Results of problems suitable for these courses are rarely single num-

bers. Usually the mathematics ends in a formula or family of curves from which the student must draw some conclusions. The student is not finished until he makes a decision or recommendation based on his conclusions.

Students in these courses are required to explain fully their reasoning in analyzing the problems, and, indeed, the nature of many of the problems makes this a necessity. Consequently, the student's papers often bear greater resemblance to English compositions than to exercises in mathematics.

CONCLUSION

In conclusion, it may be stated that the function of the undergraduate engineering program is the establishment of the bases for future learning and problem-solving activity, not the conveying of factual technological background. The particular functions of the program in engineering analysis and design in the achievement of this broad objective are:

1. To help the student establish an ability to handle problems creatively.
2. To integrate the engineering sciences by problem-solving activities.
3. To enable the student to acquire scientific and technological depth in one or more areas.

Underlying all of these functions are the modes of thinking of engineering analysis and design—synthesis, analysis and evaluation. It is vital that every course in this area of analysis and design, whether its main function be establishment of creativity or integration, or extensions or combinations of these, recognize the fundamental role of all of the basic modes of thinking in the carrying out of its objectives.

NEW MEMBERS OF ASEE

As of May 13, 1958

ATKINSON, HARRY W., Assistant Professor of Civil Engineering, Louisiana Polytechnic Institute, Ruston, La. Arthur C. Thigpem, R. A. McFarland. C. E.; Engr. Drawing.

BARRY, LEWIS C., Distribution Design Engineer, Southwestern Gas and Electric Company, Shreveport, La. Edmond M. Parker, W. Leighton Collins. E. E.; Engr. Economy.

BEMIS, ALPHEUS C., Instructor in Applied Mechanics, Michigan State University, East Lansing, Michigan. Rolland T. Hinkle, Lawrence E. Malvern. Mech. & Mat.

BODNER, SOL R., Assistant Professor of Engineering, Brown University, Providence 12, R. I. D. C. Drucker, R. M. Haythornthwaite. Mech. & Mat.; Aero. & Aero. Engr.

BOWERS, ROBERT P., Instructor in Basic Engineering, University of Akron, Akron, Ohio, Earl R. Wilson, M. Bezbatchenko. M. E.; Engr. Drawing.

BRIDGE, D. E., Director of Aeronautical, Mechanical & Metallurgical Division, Ryerson Institute of Technology, Toronto 2, Ontario, Canada. F. C. Lindvall, W. Leighton Collins. Aero.; Mech.

CHEVALIER, CHARLES E., Instructor in Mechanical Engineering, The Pennsylvania State University, University Park, Pa. Jerry G. Richter, Samuel S. Lestz. M. E.; Engr. Drawing.

CHRISTIANSEN, CARL R., Associate Professor of Mining Engineering, Missouri School of Mines & Metallurgy, Rolla, Mo. Curtis L. Wilson, George B. Clark. Min. Tech.

CLACK, ROBERT W., Instructor in Chemical Engineering, Kansas State College, Manhattan, Kansas. Henry T. Ward, M. A. Durland. M. E.; Physics.

CLUTTER, ERIC S., Assistant Professor of Engineering, West Virginia Institute of Technology, Montgomery, W. Va. L. C. Nelson, J. Milton Propps. Gen. Engr.; Math.

COMLY, SAMUEL P., Instructor in Electrical Engineering, Villanova University, Villanova, Pa. J. Stanley Morehouse, Lewis E. Unnewehr. E. E.

DROWN, CLARENCE H., Associate Professor of Engineering, Sacramento State College, Sacramento 21, Calif. Edwin B. Weinberg, Norman J. Castellan. C. E.; Gen. Engr.

DUBOIS, JOHN P., Managing Editor, DESIGN NEWS, Rogers Publishing Co., Denver, Colo. Raymond V. Smith, Robert D. LaRue. Adm. Ind.

DWON, LARRY, Manager of Engineering Manpower, American Gas and Electric Service Corporation, New York 8, N. Y. Eugene W. Boehne, H. W. Gouldthorpe. Adm. Ind.

EDMINISTER, JOSEPH A., Instructor in Electrical Engineering, The University of Akron, Akron, Ohio. Paul C. Smith, Earl R. Wilson. E. E.

ELLIOTT, EUGENE C., Assistant Professor of Humanistic-Social Studies, University of Washington, Seattle 5, Wash. Jay A. Higbee, Louis P. Trimble. Hum.-Soc.; Hist.

GRAVES, HALL H., Instructor in Engineering Drawing, Newark College of Engineering, Newark, N. J. Robert M. Rights, Frank Burns. Engr. Drawing.

HAIGHT, FLETCHER M., Instructor in Engineering, Pierce Junior College, Los Angeles, Calif. Bonham Campbell, Russell L. Perry. Gen. Engr.

HALL, GEORGE P., Chairman, Mechanical Engineering Department, Bridgeport Engineering Institute, Bridgeport, Conn. William J. Owens, Jr., Theodore M. Perkins.

HOLLUB, RAYMOND M., Instructor in Aeronautical Engineering, University of Alabama, University, Ala. William

K. Rey, Colgan H. Bryan. Aero. Engr.; Mech. & Mat.

KENYON, RICHARD A., Assistant Professor of Mechanical Engineering, Clarkson College of Technology, Potsdam, N. Y. Edward B. Kear, Jr., Myron G. Mochel. M. E.; Aero. Engr.

KESSLER, CHARLES J., Associate Professor of Mechanical Engineering, University of Missouri, Columbia, Mo. G. H. Beyer, Harry L. Beach. M. E.

KLEPINGER, WALTER J., Assistant Professor of Engineering Drawing & Design, Alabama Polytechnic Institute, Auburn, Ala. Basil K. Collins, Alton S. Little. Engr. Drawing; M. E.

KUMPE, EDWARD F., Instructor in Engineering Science, Florida State University, Tallahassee, Fla. E. W. Jacunski, J. M. Plant. Engr. Sci.

LAYLE, HERBERT F., Associate Professor of Industry, University of Detroit, Detroit, Mich. G. M. Kurajian, Elihu Geer. Hum.-Soc.; I. E.

LUEBKERT, WILLIAM C. B., Instructor in Engineering, Harris Teachers College, St. Louis, Mo. Hiram E. Grant, John E. Senne. C. E.; Engr. Drawing.

LURIE, HAROLD, Associate Professor of Applied Mechanics, California Institute of Technology, Pasadena, Calif. F. C. Lindvall, D. E. Hudson. Mech. & Mat.

MANOS, GEORGE P., Assistant Professor of Civil Engineering, University of Akron, Akron, Ohio. A. M. Richards, Duane R. Keller. C. E.

MATHEWS, KENNETH W., Southern District Manager College Department, McGraw-Hill Book Co., Atlanta, Ga. Cecil P. Marion, Jr., B. J. Dasher. Adm. Ind.

MEISTER, ROBERT, Assistant Professor of Electrical Engineering, Catholic University of America, Washington, D. C. Joseph C. Michalowicz, G. E. McDuffie, Jr. E. E.; Physics.

MOORE, ARTHUR F., Instructor in Mechanical Engineering, Howard University, Washington, D. C. Kermit Keith, Matthew McC. Douglass. M. E.; Aero. Engr.

MUELLER, EDWARD E., Associate Professor of Ceramic Engineering, University of Washington, Seattle, Wash. James I. Mueller, R. J. Campbell, Jr. Ceramic Engr.; Min. Tech.

McDOW, JOHN J., Professor and Head of Agricultural Engineering, Louisiana Polytechnic Institute, Ruston, La. Arthur C. Thigpen, Woodrow W. Chew. Agr. Engr.

MCGEADY, LEON J., Professor of Metallurgical Engineering, Lafayette College, Easton, Pa. Kemal Feridun, Charles L. Best. Metall. Tech.

NOYES, ROY B., Instructor in Mechanical Engineering, Oregon State College, Corvallis, Ore. Louis Slegel, Wesley W. Smith. M. E.; Mech. & Mat.

O'GORMAN, JOHN M., Professor and Chairman of Chemistry, Pratt Institute, Brooklyn, N. Y. Herman Krinsky, Warren E. Wilson. Chem.; Hum.-Soc.

OLESON, KENNETH S., Assistant Professor of Engineering Extension, Iowa State College, Ames, Iowa. G. Ross Henninger, Glenn Murphy. Tech. Inst.; E. E.

PAVLASEK, TOMAS J. F., Associate Professor of Electrical Engineering, McGill University, Montreal, Quebec, Canada. J. B. Phillips, W. H. Gauvin. E. E.; Physics.

PERQUIN, NICHOLAS, Assistant Professor of Mechanical Technology, State University of New York, Agricultural and Technical Institute, Alfred, N. Y. George Whitney, J. F. McMahon. M. E.; Tech. Inst.

PETERS, SAMUEL E., Instructor in Mathematics and Engineering, Long Beach City College, Long Beach, Calif. Bonham Campbell, Russell L. Perry. Math.

RIEDEL, JOHN K., Instructor in Mechanics, United States Air Force Academy, Denver, Colo. Archie Higdon, F. R. Bonanno. Mech. & Mat.; M. E.

SANDERS, JOHN P., Associate Professor of Chemical Engineering, University of Arkansas, Fayetteville, Ark. C. W. Oxford, C. W. Yantis. Chem. Engr.

SANTIAGO-MELENDEZ, MIGUEL, Instructor in General Engineering, University of Puerto Rico College of Agriculture & Mechanic Arts, Mayaguez, Puerto Rico.

Luis M. Perez Cordero, F. Acaron-Ortiz. C. E.

SKEELS, DELL R., Associate Professor of Humanistic-Social Studies, University of Washington, Seattle, Wash. Jay A. Higbee, Wesley Hunner. Hum.-Soc.; English.

STAUB, ALBERT E., Instructor in Technical Institute, University of Dayton, Dayton, Ohio. D. C. Metz, Richard R. Hazen. Tech. Inst.; Econ.

THRELKELD, WILLIAM A., Instructor in Mathematics, Tri-State College, Angola, Ind. Paul A. Nurnberger, Robert C. Foster. Math.

WEAVER, LYNN E., Associate Professor of Electrical Engineering, University of Arizona, Tucson, Ariz. John N. Warfield, Fritz Friedlaender. E. E.

WHITLOCK, BAIRD W., Assistant Professor of Humanities, Case Institute of Technology, Cleveland, Ohio. Robert L. Shurter, Melvin Kranzberg. Hum.-Soc.

WHITTERN, HARRY N., Assistant Professor of Mathematics, Tri-State College, Angola, Ind. Paul A. Nurnberger, Robert C. Foster. Math.; Physics.

WRIGHT, HAROLD E., Assistant Professor of Mechanical Engineering, University of Dayton, Dayton, Ohio. Jesse H. Wilder, Harold Nielsen, M. E.

50 new members this list
951 members previously added this year

1,001 new members this fiscal year

As of June 4, 1958

ABBOTT, EARL G., Manager Sales Training, Apparatus Sales Division, General Electric Company, 1 River Road, Schenectady 5, New York. D. E. Irwin, W. Scott Hill. Admin. Indus.

ATWOOD, KENNETH WARD, JR., Assistant Professor of Electrical Engineering, University of Utah, Salt Lake City, Utah. L. Dale Harris, Raymond A. Davidson. E. E.; Phys.

AUST, MART LEE, JR., Instructor in Mechanical Engineering, Mississippi State University, State College, Miss. Charley Scott, A. G. Holmes. M. E., Mech. & Materials.

BENJAMIN, JAMES C., Senior Professional Employment Representative, Standard Oil Company of California, 225 Bush Street, San Franciscmo 20, Calif. Admins. Indus.

BRUEHL, WILLIAM O'NEAL, Assistant Professor of Mechanical Engineering, Northeastern University, Boston, Mass. Alvin J. Yorra, Ralph S. Blanchard, Jr. M. E.; Mech. & Materials.

BRYANT, PAUL T., Assistant Editor, Engineering Experiment Station, University of Illinois, Urbana, Ill. W. Leighton Collins, R. J. Martin. English; Human.-Soc.

CARLSON, ALAN MICHAEL, Instructor in Chemical Engineering, The University of Tennessee, Knoxville, Tenn. R. M. Boarts, John W. Prados. Chem. E.; Math.

CASSIDY, JOHN FRANCIS, Instructor in Engineering, Everett Junior College, Everett, Wash. Edward W. Kimbark, Robert F. Viggers.

CIESLA, MATTHEW, Assistant Instructor in Physics, Newark College of Engineering, Newark, N. J. Leonard Shapiro, Robert Kiehl. Physics; M. E.

COBB, MCCREA H., Assistant to Director of Personnel, Hazeltine Corporation, Port Washington, N. Y. Charles E. Schaffner, Charles T. Oergol. Administrator Indus. Human.-Soc.

DEVORE, PAUL WARREN, Assistant Professor of Industrial Arts, State University of New York Teachers College

at Oswego, Oswego, N. Y. Irwin Wladaver, Lewis O. Johnson.

DEVRIES, HERBERT BOHN, Instructor in Engineering English, University of Colorado, Boulder, Colo. C. L. Eckel, Paul E. Bartlett. English; Human.-Soc.

DONAHUE, THOMAS L., Professor and Head of English and Psychology, Polytechnic Institute of Brooklyn, Brooklyn 1, New York. Charles E. Schaffner, Henry Q. Middendorf. English.

ERTEZA, AHMED, Assistant Professor of Electrical Engineering, Bradley University, Peoria, Ill. Philip Weinberg, William Hammond. E. E.; Phys.

FINE, DAVID M., Instructor in Science, Everett Junior College, Everett, Wash. Edward W. Kimbark, Robert F. Viggers.

FISK, EDWARD RAY, Instructor in Adult Education Department, Orange Coast College, Costa Mesa, Calif.; and Engineer, Hydro Sec. Bechtel Corporation, Vernon, Calif. Herbert H. Wheaton, Henry J. Hunterman, Jr. C. E.; Engr. Drawing.

FLANNERY, FRANK A., President of American Technical Institutes, Akron 8, Ohio. Thos. J. Rung, W. Leighton Collins. Tech. Inst.

GO, MATEO L. P., Assistant Professor of Civil Engineering, Syracuse University. Syracuse, N. Y. R. Ford Pray, Benjamin A. Wasil. C. E., Mech. & Materials.

GROSS, OSCAR L., Electrical Design Supervisor, United States Steel Corporation, Chicago, Ill. W. Leighton Collins, F. C. Lindvall. Admins. Indus.; E. E.

HALL, CLARENCE ELTON, Head of the Department of Engineering, Texarkana College, Texarkana, Tex. W. E. Street, B. A. Hardaway.

HANG, DANIEL FRANK, Associate Professor of Electrical Engineering, University of Illinois, Urbana, Ill. Milton H. Crothers, J. W. Bayne. E. E.; Engr. Econ.

HILL, JAMES WARREN, Associate Professor of Electrical Engineering, University of North Dakota, Grand Forks, N. D. C. J. Thomforde, E. L. Lium. E. E.; Phys.

HOFFMANN, CLINTON KELLY, Professor of Engineering Drawing, University of Kentucky, Lexington, Ky. D. K. Blythe, A. L. Chambers. Engr. Drawing.

HOOK, ELWYN T., Assistant Professor of Physics and Mathematics, Lowell Technological Institute, Medford, Mass. F. Raymond Hardy, Henry E. Thomas. Phys.; Math.

HOUSNER, GEORGE WILLIAM, Professor of Civil Engineering, California Institute of Technology, Pasadena, Calif. Alfred C. Ingersoll, D. E. Hudson. C. E.; Mech. & Materials.

JONES, ROBERT LIEN, Senior Administrative Assistant, Operations Staff, Michigan Consolidated Gas Co., Detroit, Mich.; John G. Young, W. D. McIlvaine. Admin. Indus.

KENT, BRYAN, Instructor in Civil Engineering, University of Arizona, Tucson, Ariz. D. J. Hall, E. S. Borgquist. C. E.; Human.-Soc.

KNIGHT, RAYMOND M., Senior Instructor in Mathematics, Wentworth Institute, Boston, Mass. John A. Macdonald, Harold S. Rice. Math.

LARSON, GUNNAR J., Assistant Professor of English and General Studies, College of Agriculture and Mechanic Arts, University of Puerto Rico, Mayaguez, P. R. F. Gonzales-Mandry, Robert A. Riccio. English; Human.-Soc.

LEE, CHARLES NORTHAM, Instructor in Civil Engineering, Syracuse University, Syracuse 10, N. Y. R. Ford Pray, Louis J. Goodman. C. E.; Mech. & Materials.

LEWIS, ALBERT DALE M., Associate Professor of Structural Engineering, Purdue University, West Lafayette, Ind. John M. Hayes, E. O. Stitz.

LOVE, WESLEY, Instructor in Mathematics and Mechanics, University of Cincinnati, Cincinnati, Ohio. Robert H. Rakel, A. C. Herweh. Phys.; Math.

MAHROUS, HAROUN, Associate Professor of Electrical Engineering, University

of Illinois, Urbana, Ill. M. A. Faucett, M. E. Van Valkenburg. E. E.

MANGELSDORF, CLARK PARKER, Instructor in Civil Engineering, University of Illinois, Urbana, Ill. David A. Day, Ellis Danner. C. E.; Geo. Engr.

MILKS, DONALD E., Instructor in Civil Engineering, University of Arizona, Tucson, Ariz. E. S. Borgquist, D. J. Hall. C. E.; Mech. & Materials.

MURPHY, FRED, Editor, Addison Wesley Publishing Co., Inc., North Abington, Mass. John F. Lee, J. S. Doolittle. Admin. Indus.

MCKAY, JUAN BAUTISTA, Professor, University of Panama, Panama, R. de P. W. Leighton Collins, F. C. Lindvall. C. E.; M. E.

NEMEC, ANTHONY ORVILLE, Assistant Professor of Engineering, Memorial University of Newfoundland, St. John's, Newfoundland, Canada. R. T. Liddicoat, John C. Kohl. C. E.; Engr. Drawing.

OSTERBROCK, CARL HENRY, Instructor in Electrical Engineering, University of Cincinnati, Cincinnati, Ohio. Richard H. Engelmann, Robert H. Rakel. E. E.; Math.

PARSONS, JAMES ALBERT, JR., Chairman, School of Engineering, Tennessee Arts and Industrial State University, Nashville, Tenn. Fred J. Lewis, William H. Rowan. Admr. Educ.; Metall.

ROWLAND, WALTER FRANCIS, Instructor in Civil Engineering, University of Illinois, Urbana, Ill. David A. Day, George A. Young. C. E.

SLAGLE, JACK ROBERT, Supervisor of Education and Training, Chrysler Missile Division, Chrysler Corporation, Flushing, Mich. Roland A. H. Benson, John K. McEvoy.

SODERBERG, RICHARD R., Educational Adviser (Technical Education) United States Foreign Aid Program, American Embassy-New Delhi (State Department Mail Room, Washington 25, D. C.) D. M. Wilson, R. E. Vivian. Admin. Educ.; Tech. Inst.

STRUNK, MAILAND RAINEY, Associate Professor of Chemical Engineering, University of Missouri School of Mines and Metallurgy, Rolla, Mo. Frank H. Conrad, Dudley Thompson. Ch. E.; Min. Tech.

TAYLOR, ROBERT HUGH, JR., Research Assistant in Civil Engineering, California Institute of Technology, Pasadena, Calif. Alfred C. Ingersoll, F. C. Lindvall. E. E.; Indus. E.

TANYOLAC, NECMI NACI, Professor of Electrical Engineering, Robert College, Muhendis Mektebi, Bebek-Istanbul, Turkey. Edgar K. Muhlhausen, Howard P. Hall. E. E.; I. E.

TOWFIK, NISSIM M., Instructor in Physics, Newark College of Engineering, Newark, N. J. Paul O. Hoffman, Bernard A. Greenbaum. Phys.

WELCH, AUSTIN H., Canaan, New Hampshire. W. Leighton Collins, F. C. Lindvall.

YARBOROUGH, KEITH AINSWORTH, Instructor in Civil Engineering, University of Illinois, Urbana, Ill. George A. Young, David A. Day. C. E. (Sanitary Engr.)

49 new members this list

1,001 members previously added this year

1,050 new members this fiscal year